Socially Interactive Robots as Mediators in Human-Human Remote Communication

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Abstract

This PhD work was partially supported by the European LIREC project (Living with robots and interactive companions) a collaboration of 10 EU partners that aims to develop a new generation of interactive and emotionally intelligent companions able of establishing and maintaining long-term relationships with humans. The project takes a multi-disciplinary approach towards investigating methods to allow robotic companions to perceive, remember and react to people in order to enhance the companion's awareness of sociability in domestic environments. (e.g. remind a user and provide useful information, carry heavy objects etc.). One of the project's scenarios concerns remote human-human communication enhancement utilising autonomous robots as social mediators which is the focus of this PhD thesis.

This scenario involves a remote communication situation between two distant users who wish to utilise their robot companions in order to enhance their communication and interaction experience with each other over the internet. The scenario derived from the need of communication between people who are separated from their relatives and friends due to work commitments or other personal obligations. Even for people that live close by, communication mediated by modern technologies has become widespread. However, even with the use of video communication, they are still missing an important medium of interaction that has received much less attention over the past years, which is touch.

The purpose of this thesis was to develop autonomous robots as social mediators in a remote human-human communication scenario in order to allow the users to use touch and other modalities on the robots. This thesis addressed the following research questions: Can an autonomous robot be a social mediator in human-human remote communication? How does an autonomous robotic mediator compare to a conventional

computer interface in facilitating users' remote communication? Which methodology should be used for qualitative and quantitative measurements for local user-robot and user-user social remote interactions?

In order to answer these questions, three different communications platforms were developed during this research and each one addressed a number of research questions. The first platform (AIBOcom) allowed two distant users to collaborate in a virtual environment by utilising their autonomous robotic companions during their communication. Two pet-like robots, which interact individually with two remotely communicating users, allowed the users to play an interactive game cooperatively. The study tested two experimental conditions, characterised by two different modes of synchronisation between the robots that were located locally with each user. In one mode the robots incrementally affected each other's behaviour, while in the other mode, the robots mirrored each other's behaviour. This study aimed to identify users' preferences for robot mediated human-human interactions in these two modes, as well as investigating users' overall acceptance of such communication media. Findings indicated that users preferred the mirroring mode and that in this pilot study robot assisted remote communication was considered desirable and acceptable to the users.

The second platform (AiBone) explored the effects of an autonomous robot on human-human remote communication and studied participants' preferences in comparison with a communication system not involving robots. We developed a platform for remote human-human communication in the context of a collaborative computer game. The exploratory study involved twenty pairs of participants who communicated using video conference software. Participants expressed more social cues and sharing of their game experiences with each other when using the robot. However, analysis of the interactions of the participants with each other and with the robot show that it is difficult for participants to familiarise themselves quickly with the robot while they can perform the same task more efficiently with conventional devices.

Finally, our third platform (AIBOStory) was based on a remote interactive story telling software that allowed users to create and share common stories through an integrated, autonomous robot companion acting as a social mediator between two people. The behaviour of the robot was inspired by dog behaviour and used a simple computational memory model. An initial pilot study evaluated the proposed system's use and acceptance by the users. Five pairs of participants were exposed to the system, with the robot acting as a social mediator, and the results suggested an overall positive acceptance response. The main study involved long-term interactions of 20 participants in order to compare their preferences between two modes: using the game enhanced with an autonomous robot and a non-robot mode. The data was analysed using quantitative and qualitative techniques to measure user preference and Human-Robot Interaction. The statistical analysis suggests user preferences towards the robot mode. Furthermore, results indicate that users utilised the memory feature, which was an integral part of the robot’s control architecture, increasingly more as the sessions progressed.

Results derived from the three main studies supported our argument that domestic robots could be used as social mediators in remote human-human communications and offered an enhanced experience during their interactions with both robots and each other. Additionally, it was found that the presence of intelligent robots in the communication can increase the number of exhibited social cues between the users and are more preferable compared to conventional interactive devices such as computer keyboard and mouse.

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Contents

Table of Figures

List of Tables

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Chapter 1: Introduction

1.1 Introduction

It has become a common trend for some people to be distant or even isolated from their relatives and friends due to work commitments or other personal obligations in our current lifestyle. The lack of communication could result in loneliness, feelings of isolation and a lack of sense of value in their relationship. Even for people that live relatively close, remote communication has become a necessity, and technology provides users with the right means of achieving this aim. Many people living away from their friends and families communicate through electronic interfaces in order to maintain their relationships. The most common communication technology used today is the telephone.

People started communicating electronically through the use of ordinary phones at the beginning of the twentieth century, while the use of video phones was considered a luxury for some later in the century. However, the field of communication changed dramatically with the arrival of digital communications and computers. Often, in particular for longer distances, people use video communication software that provides richer experiences. Video conferencing is now common in households, provided they have a computer and internet access; however, even with the use of video communication, users are missing an important medium of interaction that has received far less attention – touch (Fong, Nourbakhsh, & Dautenhahn, 2003). Touch between humans have shown positive health and psychological results such as an increase of relationship bonding, lowering the stress levels, communicate emotions and affecting the trust (Fisher, Rytting, & Heslin, 1976; Guéguen, 2002). Increasingly, researchers have been studying how touch could be transferred over communication channels in order to enhance users' experiences and provide more interactive and enjoyable encounters. The sense of touch directly relates to the skin, which played a major role in early human development because it is the first sensory organ to develop (Montagu, 1987). In the context of remote communication, and especially in this thesis, the enhancement of user experience is defined as the increase of social cues, tactile interaction and enjoyable communication. These measures are quantifiable and can highlight differences in comparative studies investigating tactile and non-tactile interfaces. An example of a tactile interface through remote communications might include a device worn by the user (e.g. tactile gloves (Folgheraiter & Vercesi, 2005)) or robots in various forms and shapes, which have been used for domestic entertainment purposes by offering advanced social interactions with humans (Fong et al., 2003).

Robots nowadays are offered with various embodiments such as dog like, dinosaurs, wheeled robots etc. Usually, a robot's embodiment is equipped with various sensors in order to sense and realise the environment, the surroundings and user input. A robot could be either autonomous or semi-autonomous depending on its hardware and intended interactants. In the context of remote communication enhancement, a semi-autonomous robot can perform various actions independently but mainly its behaviours are controlled by humans. However, in the same context, an autonomous robot interacts with the environment through its actuators and sensors and performs behaviours in self-sufficient manner for an extended period without human intervention. There are various types of robots suitable for domestic environments and others for industrial use, however this thesis will focus on the former. Domestic robot in homes must comply with some social rules in order to ‘fit’ well in the environment and behave appropriately to the residents. A definition of a ‘social robot’ is proposed by Bartneck & Forlizzi:

> “A social robot is an autonomous or semi-autonomous robot that interacts and communicates with ‘human’ by following the behavioural norms expected by the people with whom is intended to interact” (Bartneck & Forlizzi, 2004).

Additionally, Breazeal defines the term social robots as robots that proactively engage with humans in order to satisfy their internal drives (Breazeal, 2002; Breazeal, 2004). Dautenhahn extends the definition for the social role of robots where robots show aspects of human-style social intelligence (Dautenhahn, 1998).

In the context of remote communication, a domestic robot could be utilised as “social mediator” in order to enhance the remote communication. Dautenhahn points that in order for a robot to be really effective as social mediator it has to be socially embedded, part of and ‘aware’ of the social environment (Dautenhahn, 2003). Robots as social mediators can enhance the remote communication experience by actively participating with the remote users and utilising its embodiment as a physical interaction device directly available to the users. Utilising robots as social mediators in the communication channel is of paramount significance as they offer the ability of immediate integration with personal computers. This ability can be exploited in order to offer interactive content to computer users who communicate with their computers using video conferencing technologies. Robots can simultaneously interact with users and computers offering an interactive experience that could be transferred to a remote end. Users can verbally and physically interact with the robots and over time they can build a bond with the robot and especially with robots capable of running in autonomous mode. A socially interactive robot can learn and develop social competencies, create and maintain social relationships, demonstrate unique personalities, express emotions, recognise other robots and communicate with high-level dialogue (Dautenhahn, 2007a). The social aspect of Human-Robot Interaction could be transferred over a network channel in order to socially connect two or more users with the help of similar type of hardware.

Robots are occasionally used in domestic environments where people co-habit and it is believed that the number will keep increasing in the coming years (Chen, Chen, & Chase, 2009). A robot companion could be described as a robot that is useful in everyday home tasks in order to help humans and at the same time to behave socially in order to interact with people in a socially acceptable manner. In the European LIREC project (Living with Robots and interactive Companions) a collaboration of 10 EU partners aims to develop a new generation of interactive and emotionally intelligent companions able of establishing and maintaining long-term relationships with humans. The project takes a multi-disciplinary approach towards investigating methods to allow robotic companions to perceive, remember and react to people in order to enhance the companion's awareness of sociability in domestic environments. At the University of Hertfordshire we are mainly involved on the Human-Robot Interaction aspects of the project. One of the scenarios involved two distant users who wish to communicate utilising robots as social mediators for an enhanced experience. Our research group investigates the role of robots in everyday tasks in domestic environments. Here, the robots function as cognitive prosthetics (e.g. remind a user and provide useful information) or they provide physical assistance (e.g. carry heavy objects). Another key scenario in LIREC project aims at developing autonomous robots as social mediators. This scenario involves a remote communication situation between two distant users who wish to utilise their robot companions to enhance their communication and interaction experience with each other over the internet. This scenario derived from people how wanted to remotely interact with their distant relatives and friends, as ordinary face-to-face communication are limited due to work commitments or other personal obligations. The scenario employs companion robots that run in autonomous mode in a home environment capable of wirelessly connecting to the computer to establish and facilitate a remote communication between two users. The objectives of this scenario were to increase the enjoyment between the users as well as the number of exhibited social cues.

This scenario required two distant users sitting in their offices in front of their computer to communicate by using robots small enough to move around on the table and satisfy the Human-Robot and human-human interactions. For that reason we chose a small but yet very well performing interactive robot, the AIBO ERS7 model from SONY which has been previously used by many researchers and showed positive acceptability from the users, e.g. in (Bartneck, Suzuki, Kanda, & Nomura, 2006). AIBO is a dog-like robot with multiple embedded sensors and actuators with wireless capabilities and a processor powerful enough to perform realistic dog-like behaviours required in our scenario. A dog-like robotic companion can be proven beneficial in Human-Robot Interaction as comparable studies have shown that animals as therapeutic companions offer great benefits to people, including: lowering stress levels (Allen, Blascovich, Tomaka, & Kelsey, 1991), reducing heart rate (Ballarini, 2003) and enhancing social facilitation (Collis & McNicholas, 1998). Additionally, animal replacement robots are also suited for cases where it is impractical and unsafe to use real animals due to dangers from e.g. bites, allergies and diseases (e.g. hospitals). In order to enhance the remote communication beyond the traditional voice and video information, the robot must offer a novel experience to both users.

An autonomous robot can provide touch interactions to the users that could be potentially shared over the communication channel for an enjoyable human-robot to robot-human experience (Chapter 2, Remote communication enhancement). The robot can perform various behaviours that users can interact and learn from them (Chapter 2, Remote expressions). Robots utilised as social mediators will allow the users to share and exchange their experiences from the autonomous robots as each user reacts differently. Furthermore, autonomous robots can adapt to a user attitude and develop their own artificial personality that will be used towards behaviour planning. This unique artificial personality that has been developed through multiple long-term Human-Robot Interaction could be transferred over the communication channel from the robots (Chapter 2, Human-Robot Interaction). Additionally, two distant robots could intentionally link their behavioural drives over the network in order to remotely mirror their personality to the users. This “mirroring” effect could enhance users’ awareness of being together and working/playing with the same robot as it can replicate the same behaviours (Chapter 2, Telepresence). The experience sharing over the internet will bring a new dimension to the users who seek to communicate via an enhanced method that includes collaborative tools to enable them to express social cues between them.

Remote communication enhancement is a growing field that requires deep research to reveal the real benefits of it. Using autonomous robots to enhance the communication and generally make the communication more enjoyable is a promising field that has not received much attention as shown in the literature review in Chapter 2 and we believe that an intelligent robotic companion system could fill this research gap. In order to validate results from studies alike, a suitable measuring methodology should be used to extract any positive or negative results regarding the communication enjoyment and preference. For that reason it is very important to compare the results with existing communication technologies, for instance conventional computer interfaces with autonomous robotic companions. Such comparisons will allow us to draw valid conclusions about our research and will also direct our futures studies.

1.2 Research questions

- RQ1*: Can an autonomous robot be a social mediator in human-human remote communication?*
- RQ2: *How does an autonomous robotic mediator compare to a conventional computer interface in facilitating users' remote communication?*
- RQ3: *Which methodology should be used for qualitative and quantitative measurements for local user-robot and user-user social remote interactions?*

The hypothesis drawn from the introduction and the literature review in the related research areas is that an autonomous robot can enhance a remote communication between two distant users. We anticipate that robots on both remote ends can deliver a novel method of interaction between the users as they provide a shared tangible hardware. Furthermore, we believe that a robotic companion will be desirable for long-term interaction as a social mediator since the behaviour architecture can adapt to users' preferences thus providing them a personalised interaction and information for users to share. Additionally, we believe that a suitable methodology for comparing and analysing social mediating technologies should exist in order to provide to the researchers useful information for their related studies.

1.3 Methodology

In order to evaluate the role of a robot companion as a social mediator, a remote communication system had to be developed. This system in short, consists of a programmable robot which runs autonomously and a computer interface which is directly connected to the robot. The same setup is replicated in a remote location where both robots and computer interfaces are remotely connected and synchronised. The communication platform required a number of hardware devices such as two AIBO robots, two desktop or laptop computers, two network routers and two cameras to record participants' behaviours. The different hardware devices required specific programming languages and especially the robots requiring URBI (Universal robotic language (Baillie, 2004)) which was used extensively in order to allow our system to be used with different robotic embodiments.

Since this PhD focuses on Human-Robot Interaction, the system had to be evaluated with multiple participants. In total, 90 participants were recruited for our studies and each one received an explanatory user manual and a small demonstration of the system in order to familiarise themselves with the robots. Ethics approval was granted as part of the LIREC project prior to the studies. Long- and short-term studies took place during this PhD and three remote communication systems were developed, tested and evaluated by the author of this Thesis. For each study we used multiple logged material to analyse behaviours, performance and other aspects of the communication. The software packages IBM SPSS[1] and Microsoft Excel 2007[2] were extensively used to statistically analyse the generated data and plot the resulted figures and graphs. In order to analyse the video data for each participant, we had to use a video coding software for behavioural analysis. We decided to use the Observer [3]from Noldus which allowed us to create various coding schemes and analyse participants' behaviours. Observer software allowed us to extract significant results and group them into categories for further analysis. The author of this thesis was the main video coder of the videos. In order to validate the video data, as part of a well-established procedure, we trained an external observer to code 20% of the videos and compared the new findings with our results (Fleiss, Levin, & Paik, 2004).

Each study produced significant results and along with the participants' feedback we used these information to guide the development of the next communication system.

1.4 Contribution to knowledge

This research focuses on novel methods for enhancing remote communication between two distant users by introducing domestic robots on both sides, acting as social mediators. The purpose of this research is to identify possible and acceptable Human-Robot Interaction techniques that support and strengthen the hypothesis regarding the robot's social mediator role. Similar research has been done in the field of remote communication enhancement technologies however, this PhD research will focus on Human-Robot Interaction studies and the modelling of natural pet-like behaviours utilising commercially available domestic robots. Furthermore, the findings of this research will

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[1] IBM SPSS, http://www-01.ibm.com/software/analytics/spss/

[2] Microsoft Excel 2007, http://office.microsoft.com/en-gb/excel/

[3] Noldus Observer XT, http://www.noldus.com/human-behavior-research/products/the-observer-xt

offer a generic framework for future communications by utilising any available robot that is capable of perceiving user feedback, reacting to the environmental changes and expressing behaviours based on its internal states.

Moreover, this PhD research will investigate the impact of memory and adaptation on long-term Human-Robot Interaction in remote communication scenarios. The results of this study will contribute towards the improvement of the proposed remote communication architecture as well as on similar communication systems that involves long-term interactions between two users. Additionally, this research intends to provide an overall better understanding for the appropriate methodology in regards to capturing, coding and evaluating various metrics generated from the experiments when utilising robots as social mediators for remote communications.

1.5 Overview of the thesis content

This chapter introduced the broad subject areas of interest and also highlighted the research questions which will be addressed in the next chapters. Additionally, it lists the contributions to knowledge and the methodology that was used for this PhD.

Chapter 2: This chapter lists and analyses relevant research. It introduces the Human-Robot Interaction terms and lists related research along with Human-Computer interaction. Additionally, it explains the importance of touch on distant communication and lists various projects that simulate this sense over distance. Finally, this chapter ends with a short discussion regarding their relevance with to PhD project.

Chapter 3: This chapter analyses the development of the social mediator platform. It studies the selected choices and their rationale in order to achieve the required goal to answer this thesis research questions. Additionally, it lists the required material for each study along with their setup.

Chapter 4: This chapter describes the implementation, testing and evaluation of the first prototype of the "AIBOcom" system, which allows remote users to play an interactive game cooperatively each using a pet-like robot as a social mediator. An exploratory pilot study tested this remote communication system with 10 pairs of users (20 participants). Significant correlations were found and presented between the users as well as users' preferences and overall acceptance of such communication media.

Chapter 5: This chapter studies the effects of an autonomous robot on human-human remote communication in comparison with a conventional mode by using keyboard and mouse. Twenty pairs of users (40 participants) participated in this comparative study. Each pair of participants utilised both the robotic and the conventional devices to play an interactive game while they communicated using video conference software. Results revealed multiple significant results regarding social cues and experience sharing over the network.

Chapter 6: In this chapter we present AIBOStory. AIBOStory is remote interactive story telling software that allows users to create and share common stories through an integrated, autonomous robot companion acting as a social mediator. Five pairs (10 participants) were exposed to the system, with the robot acting as a social mediator, and the results suggested an overall positive acceptance response. The system was later evaluated through a long-term study which involved 10 pairs (20 participants) in order to compare their preferences between a robot that utilises a computational memory model and a non-robot mode. Significant correlations were found, which suggest user preference towards the robot mode, while the questionnaire and logged data indicate a fairly significant leaning towards interaction between the user and the robot.

Chapter 7: Finally, this chapter summarises the results of the three studies and discusses their significance to the field. Furthermore, it concludes and provides a list of limitations of the current implementations and highlights the contributions to knowledge. Additionally, it provides guidelines and roadmap for future developing of social mediator communication platforms based on lessons learnt from the previous studies.

1.6 Publications list

During my research at the University of Hertfordshire, I submitted four research papers to conferences, Journals and book editors. I was the main author on all studies and papers. My supervisors guided me and supported my studies during the design, development and evaluation process as well as editing the produced papers.

The first two papers contributed to Chapter 4. The third and fourth papers contributed to Chapter 5 and Chapter 6 respectively.

Publications:

1. Papadopoulos, F., Dautenhahn, K., & Ho, W. C. (2013). Behavioral Analysis of Human-Human Remote Social Interaction Mediated by an Interactive Robot in a Cooperative Game Scenario. In R. Luppicini (Ed.), Handbook of Research on Technoself: Identity in a Technological Society (pp. 637-665). Hershey, PA: Information Science Publishing. doi:10.4018/978-1-4666-2211-1.ch033

2. Papadopoulos, F., Dautenhahn, K., & Ho, W. C. (2010). AIBOcom: Designing Robot Enhanced Human-Human Remote Communication Technology. Proceedings of the Kansei Engineering and Emotion Research International Conference 2010 (KEER2010). Paris, France.

3. Papadopoulos, F., Dautenhahn, K., & Ho, W. C. (2012). Exploring the use of robots as social mediators in a remote human-human collaborative communication experiment. Paladyn, 3(1), 1–10. doi:10.2478/s13230-012-0018-z

4. Papadopoulos, F., Dautenhahn, K., & Ho, W. C. (2012). AIBOStory – Autonomous Robots supporting Interactive, Collaborative Story-telling (Submitted to Journal)

Chapter 2: Background and related research

2.1 Human-Robot-Interaction (HRI)

Human-human communication with robots as social mediators is a relatively new research field that utilises Human-Robot Interaction (HRI) on the remote ends. Dautenhahn, Goodrich and Schultz pointed out that various research fields such as robotics, engineering, computer science, AI, psychology, social and cognitive sciences and Human-Computer Interaction (HCI) are essential for HRI studies (Dautenhahn, 2007b; Goodrich & Schultz, 2007).

As domestic robots become more and more available to the public, scientific interest in HRI studies is growing in a fast pace. The most common domestic robots nowadays are built for specific tasks such as the Roomba[4] robot where its task is to intelligently vacuum clean a house. However, besides the role of task oriented behaviours, a robot could interact with humans in a social manner. Dautenhahn (Dautenhahn et al., 2005) and Woods (Woods et al., 2007) state that when a robot is interacting with humans it must be socially accepted and effective. Furthermore, Dautenhahn (Dautenhahn, 2007a) pointed out the necessity of social skills on domestic robots and depending on the context and their purpose they should have more or less skills. These skills, as indicated by Fong et al. (Fong et al., 2003), might be expressions of emotions, social relationships with humans, social cues, unique personality and communication.

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[4] iRobot, Roomba robot, http://www.irobot.com/global/en/store.aspx

Figure 1: AIBO ERS-7 robot

Nowadays, the advanced technological state of personal robots allowed the researchers to use the robots as entertainment tools for their owners as the robots are capable of social and intelligent interactions with humans (Salichs et al., 2006). Studies (cf. (Breazeal, 2004; Breazeal, 2004)) have publicised how robots can interact and express emotions in a social manner with humans. On the other hand, although robots can express and receive social cues such as tactile or voice information from their owners, users do not feel the same way for AIBO (Figure 1) robots when comparing the latter to animals (cf. (Friedman, Kahn, & Hagman, 2003)). Friedman et al. showed that participants engaged with their AIBOs psychologically during their long-term interactions however, they did not attributed moral standings towards the robots the same way they do with real animals. In order to avoid an overall negative social predilection from the users towards the robots, Breazeal (Breazeal, 2003b) proposed a framework that would design and evaluate sociable robots while viewing the problem from both the robot's and human's perspective at the same time. Moreover, Steinfeld et al. (Steinfeld et al., 2006) developed a framework that identifies common metrics and biasing factors for task-oriented Human-Robot Interaction that must be taken into consideration when designing and developing a system. Furthermore, Steinfeld et al. point out the importance of selecting participants that combine a broad range of knowledge and experience for the experiments. A proper recruitment would effectively utilise the proposed metric thus producing more significant results.

Sidner et al. (Sidner, Lee, Kidd, Lesh, & Rich, 2005) explored the engagement process between humans and robots during interactions. This study focused on the engagement among human interactors (face tracking while an interaction is taking place). Sidner et al. analysed a robot architecture that supports conversational interactions with engagement gestures and tested the system by utilising two interactive modes: a mode with a robot supporting engagement gestures and a mode with a non-gesture robot. Results from the studies indicate users' preference towards the mode with the engagement gestures as users directed their attention to the robot with gestures more often and furthermore, deemed that the interaction was more appropriate in that mode than in the non-gesture one. Moreover, the Mel robot (Sidner, Kidd, Lee, & Lesh, 2004) (Figure 2) was designed to mimic a conversational human gaze behaviour in Human-Robot Interaction. This robot was custom made by Mitsubishi Electric Research Labs which was given the appearance of a penguin in an attempt to make it more user-friendly. The authors of this study, proved the importance of mutual human-robot gaze and by large the importance of the robot’s gaze as a necessity in order to achieve and maintain a successful user-robot engagement.

Figure 2: Mel, the robotic Penguin, created at Mitsubishi Electric Research Labs (Sidner et al. 2004), image is used with permission from C. Sidner

Metrics in Human-Robot Interaction

Mutuality and synchronisation are two very closely related terms when it comes to recognising engagement in Human-Robot Interaction (Rich, Ponsleur, Holroyd, & Sidner, 2010). A computational model derived from results of previous studies has been created in order to recognise the engagement between Humans and Robots. In particular, this model includes four event recognisers for detecting direct gaze, mutual face gaze, conversational adjacency pairs and backchannels (a brief verbal or gestural communication from the responder back to the initiator). In order to validate the model used, the authors compared two scenarios between Human-Human and Human-Robot task. The Human-Human task involved a participant who was instructed how to make various kinds of canapés by using a variety of materials and then the instructor was replaced with a second participant to be taught by the first participant. For the Human-Robot study, the authors created and tested a pointing game which involved a small sample of participants and a robot. In this game, participant and robot sat in front of a table with multiple objects and either the human or the robot replicated the behaviours as instructed by the initiator (human or robot). They then compared the results between the

Human-Human and the Human-Robot observational data and identified a positive preliminary validation of their model. In addition to this particular model, other researchers also studied and identified common metrics for Human-Robot Interaction (see a review in (Steinfeld et al., 2006)). Guo and Sharlin (Guo & Sharlin, 2008) performed an HRI study with a 3D tangible user interface as a test bed to explore a robotic navigation control and a robotic posture control to be used with an AIBO robot. To capture users' movements and hand gesture for Human-Robot Interaction they used a Nintendo Wiimote control and Nunchuk. They performed a comparison study between the proposed tangible system and a conventional input device in terms of accuracy and speed. Their results suggested that the tangible user interface performs better than the conventional system as the users required less time to finish the task and at the same time made less mistakes. Moreover, users preferred the tangible user interface over the conventional one as an input device for controlling the robots.

Heerink et al. (Heerink, Krose, Evers, & Wielinga, 2008) researched the influence of social presence for robot acceptance and more specifically, the social abilities, perceived enjoyment and social presence. In particular, they performed two studies with participants in the elderly group age, where they used a robot with less social abilities than the robot of the second experiment. The results suggest that the latter mode (more social abilities) perceived higher scores in social presence and enjoyment, which namely represents higher intention to use this system. Having robots in our daily routine is another study that Mitsunaga et al. (Mitsunaga, Miyashita, Ishiguro, Kogure, & Hagita, 2006) performed with a human-sized robot wandering around an office environment (Figure 3). This long-term study focused on Human-Robot communications and more specifically, on social interactions. Mitsusaga et al. also proposed four basic design requirements for social robots: a) a robot should be self-contained and autonomous b) it should have haptic capabilities c) it should be able to perform involuntary motions and d) to have human recognition.

Figure 3: Robot in office environment (Mitsunaga et al. 2006), image is used with permission from M. Mitsunaga

Although the shape of Mitsunaga et al. robot platform was machine based, Walters et al. (Walters, Dautenhahn, Syrdal, Te Boekhorst, & Koay, 2008) explored the users' preferences with regard to robot appearance and behaviours. Walters et al. performed a user study with various robotic shapes and behaviours and found out that users showed a preference towards robots with human-like appearance and behaviours. They also stressed out that users tend to expect certain capabilities depending on the robot's appearance. Additionally, Walters et al. (Walters, Dautenhahn, Boekhorst, Koay, & Woods, 2007) discovered from their video based HRI studies that users rate specific robot's behaviours less favourably when the robot's appearance is not consistent with the performed behaviour. In addition, their results indicated that users' ratings with regards to robot's appearance are influenced by the robot's behaviours. Therefore, based on these findings, robot design should be carefully considered and an appropriate robot appearance should be selected after considering the required task. A more careful consideration should be taken especially when robots are designed to interact in human environments as it has major implications on Human-Robot Interaction.

Bruce et al. (Bruce, Nourbakhsh, & Simmons, 2002) performed a Human-Robot Interaction study in order to measure the impact of specific and predefined robot behaviours on users willingness to initiate a successful interaction with the robot. They chose a minimalistic approach for robot interaction in order to reduce the requirements for an effective Human-Robot Interaction. In this study, the researchers utilised a humanoid face for expressions and attention seeking, while they programmed the robot to face the addressed users. Their initial results showed that the robot's attention seeking behaviours towards the users, did not increase the participants' interest for interaction as the researchers expected. This result indicates the importance of carefully designing and developing robotic behaviours in social environments and moreover, the selection of a suitable robotic appearance for use in social interactions.

2.2 Human-Computer Interaction (HCI)

Human-Robot Interaction is very closely related to the field of Human-Computer Interaction (HCI) as both research fields focus on human interactions with computer technology. Various studies in the past have shown that users treat and express social behaviours towards computers. Reeves et al. (1996) and Nass et al. (Nass, Steuer, & Tauber, 1994) have conducted several studies and concluded that users develop social relationships with computers although they are explicitly aware that computers are artificial artefacts. Consequently, it can be anticipated that users would also express similar social cues towards robots and furthermore relate to them as they commonly achieve with computers. Although, due to hardware and physical dissimilarities, it is expected that the social bond between robots and humans will be developed differently. Similarly, Kahn et al. (Kahn, Freier, Friedman, Severson, & Feldman, 2004) performed long term studies with elderly people and AIBO robots and their findings indicate that robots, even when they do not directly affect users' social behaviours, they act as mediators on human-human interactions when the robots are left with the users.

2.3 Computer-Mediated Communication (CMC)

In the 80's, computers were becoming more and more common to people and the urge of communication was increased significantly with the arrival of Internet. Users started utilising their computers to communicate through emails and later on through voice and video. Kiesler et al. (Kiesler, Siegel, & McGuire, 1984) stressed the importance of investigating the socio-psychological effects in electronic email communications at that time. They explored how people interact with each other when using electronic communications and compared them with face to face communications. Their findings showed differences in interactions, decisions and contribution among the two interaction modes as people react differently in face-to-face scenarios than depersonalised emails. Moreover, Bordia (Bordia, 1997) reviewed multiple published experiments on the same comparison between face to face (FTF) and computer mediated communications (CMC) and concluded that although CMC communication require longer time to complete, they have more equality of participation and produce more ideas on the topic. When CMC started to grow significantly in the early 90's, people were worried that the mediated communications would dehumanise interactions because of their lack of transmitted social cues between the users. Walther (Walther, 1995) studied the interpersonal messages (relational communication) in CMC in order to investigate users' relationships and compared the results with FTF communications. Results showed that users achieved more positive results in CMC as they did with FTF communications. Walther findings also suggest that CMC technologies can promote superior relational effects compared to traditional communications, which is a crucial finding that previous theories in the field have not yet considered. Beside its positive results on the increased amount of social cues in CMC, it has been successfully used widely on remote learning applications and showed its positive implications on these scenarios (Berge & Collins, 1995; Chou, 2001; Leh, 2001). Remote learning has been used for many years using computers and other communication devices such as movable video cameras, tablet computers etc. and it has proven its advantages over traditional communication equipment.

2.4 Touch-based Interaction

However, although the above mentioned technologies (CMC) have improved the interactions on distant communications, they are still missing a very important interaction cue, that has received much less attention than other interaction mediums, which is touch (Fong, Nourbakhsh, & Dautenhahn, 2002). The sense of touch directly relates to the skin, which plays a major role in early human development since it is considered to be the first developed sensory organ (Montagu, 1987). Furthermore, Wilhem et al. (Wilhelm, Kochar, Roth, & Gross, 2001) and Drescher et al. (Drescher, Gantt, & Whitehead, 1980) stressed the importance of touch on social interactions and its implications on human emotional state and anxiety as it appears to reduce the heart rate on various occasions. Moreover, touch between humans has shown to increase their bonding, reduce stress levels and increase emotions (Fisher et al., 1976). Additionally, Gueguen et al. (Guéguen, 2002) have pointed out the positive effects of physical contact in humans, as it can be catalytic in the growth of trust and attachment in human encounters. Since physical contact significantly affects communication in human-human interactions, the effects of touch have been studied between humans and robots in an attempt to improve the interactions among them and make them more 'social' (Cramer, Kemper, Amin, & Evers, 2009; Folgheraiter & Vercesi, 2005; Yohanan & Maclean, 2008). In addition, negative or positive attitudes towards robots can also affect the intention of the users to get in close proximity with the robots, which will allow easier interactions with the robots (Nomura, Kanda, Suzuki, & Kato, 2004; Walters et al., 2008).

Cramer et al. (Cramer, Kemper, Amin, Wielinga, & Evers, 2009) performed a study that included robots able to perform various touch behaviours with participants in order to explore the influences of users' attitudes towards robots. Their results indicate that user attitude towards the robots significantly affects the user's perception and relationship with the robots. Therefore, it is very important that robot behavioural design should be carefully considered and chosen prior to Human-Robot studies. Moreover, Yohanan and MacLean (Yohanan & MacLean, 2008) have developed a small robot pet that mimics a real pet's behaviours and interacts through human touch. They focus on the social aspect of touch in Human-Robot Interaction, in an attempt to explore if the affective touch can positively support companionship as this aspect has received a disproportionate attention compared to vision and voice in Human-Robot studies.

HRI studies have shown the importance of touch between users and robots although they were only focusing on local interactions. A video conference communication is nowadays very common in households, provided they have a computer and internet access. Researchers have been studying about how touch could be transferred over the communication channel to enhance the users' experience and provide a more interactive and enjoyable communication. Touch might provide more interactive and enjoyable communication if the means of interaction are designed appropriately and are acceptable by users. Such technology might even include robots or a device worn by the user (e.g. tactile gloves (Folgheraiter & Vercesi, 2005).

The touch sensation could be transferred over the communication channel along with video and voice in order to "enhance" the interaction of two or more distant users.

Remote touch could be simulated using various hardware devices or even robots and has been used extensively for remote interactions, expressions and rehabilitation.

2.5 Remote Communication enhancement

Nowadays, remote communication through computers is mandatory for social relationships and people utilise computers in order to visualise the remote user on their screens. Video conferencing software is being used even in mobile phones and offers an enhanced communication for the distant users. However, sometimes voice and video limit the communication as users cannot use of their hands to physically interact with each other. Researchers have been working in this field in order to introduce touch on remote communications and Teh et al. (Teh et al., 2008) have developed a novel communication system called the Huggy Pajama. This consists of a special wearable pyjama that is worn by a child and a huggable robotic bear. While a parent is away from the child, they can hug the robotic bear, which has embedded pressure sensors, and the hug is transmitted to the child via inflatable pads in the Pajama.

Similar to this project is also the "Hug over distance" (Mueller et al., 2005) which uses the same hardware to simulate the distant hug, although it focuses on couples rather than parent to child interaction. However, the system requires special hardware vest, which may be difficult to acquire and may be unacceptable to users, especially children. Furthermore, in order to "sense" the distant hug, users are required to wear the special vest continually which might be impractical or unacceptable for long-term use. Likewise, an intelligent vest could be used for therapy governed from distance. Bonanni et al. (Bonanni, Vaucelle, Lieberman, & Zuckerman, 2006a) have designed, developed and tested a wearable touch sensitive jacket that allows two people to exchange tactile information in an asynchronous way for nurture and affection in order to support emotional therapy. Their system includes sensors for capturing and recording the tactile information and actuators to play back the recorded types of human contact asynchronously. Pilot studies with participants showed positive results and pointed out further improvements to the system. Similarly, Gemperle et al. (Gemperle, DiSalvo, Forlizzi, & Yonkers, 2003) developed a remote communication system that includes two mechanical bears on both ends to simulate the human hug over distance. Their system is mainly for elderly users who are away from their family members and need something more than just voice and video. It supports voice and tactile communication between the users such as talking, squeezing, hugging and petting the mechanical bear which will be transmitted to the remote end. Their experiments with participants showed positive results which will guide them for a better communication system suitable for long term studies.

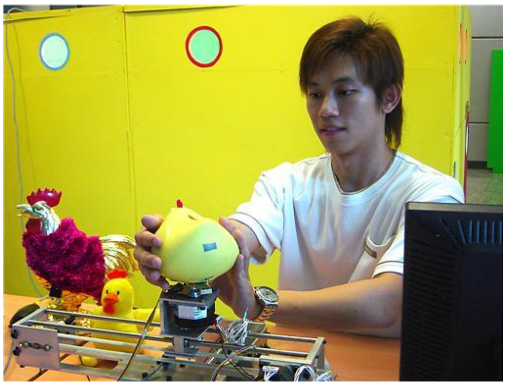

Figure 4: Poultry internet (Lee et al. 2006) Picture taken from http://mixedrealitylab.org/projects/all-projects/poultry-internet

Poultry Internet (Lee et al., 2006) (Figure 4) focuses on human to animal interaction, with similar principles to the Huggy Pajama, but uses a robotic animal to replicate the movements. When an owner leaves an animal in care with another person, the system can provide comfort to the animal as it can perceive familiar petting from the owner. However, using the system on untrained animals is problematic as they will usually remove anything attached to their body (like bandages, stitches etc.). Despite these worn devices, similar research has been done using furry bears and toy like robots such as the MIT huggable platform and Probo robot.

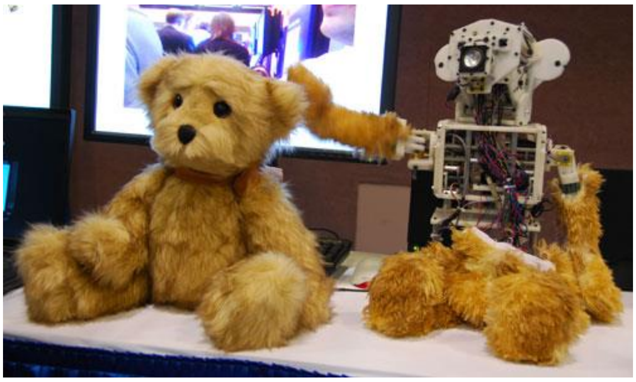

Figure 5: MIT's Huggable robot (Jun Ki et al. 2008), image is used with permission from L. Jun Ki

MIT's "Huggable" (Figure 5) is a similar project that was specifically built for the enhancement of remote communication between parents and their children (Jun Ki, Toscano, Stiehl, & Breazeal, 2008). The Huggable hardware is remotely controlled via a specifically designed web interface. The particular robot is programmed to run in a semi-autonomous mode which allows it to react to various external stimuli. A possible usage for this system could be in cases where a parent is away and would like to use the web interface to connect to the robot bear and use it to read their child a story. The Huggable platform has also been used in a study (Stiehl et al., 2006), where the focus was on the hardware aspects of the robot which aimed to perform, react and perceive similarly to a real animal.

Figure 6: The Probo robot (Goris et al. 2009), Image is used with permission from K. Goris

The Probo robot (Goris, Saldien, & Lefeber, 2009) (Figure 6) has been designed to help children to overcome the stress and pain caused by hospital stays by creating a friendlier and cosier environment for children. Probo can play games and read stories when the child feeling alone. It can also be used in collaboration with paediatricians, psychologists and sociologists for applications in the field of Robot-Assisted-Therapy (RAT). Prattichizo et al. (Prattichizzo, Chinello, Pacchierotti, & Minamizawa, 2010) developed the RemoTouch project for remote touch experiences transmitted from one place to the other. The system consists of the remote hardware which captures the tactile information from the user along with the voice and vision and transmit them over the internet to the remote user who wears force feedback gloves and virtual reality glasses. The remote user perceives the same input as the local user who transmits the data and interacts with objects. Their preliminary findings indicate that their system could be used for applications such as remote rehabilitation and generally for teleoperation between users.

In terms of collaboration over the Internet Xin and Sharlin explored Human-Robot Interaction through telepresence board games (Xin & Sharlin, 2006a, 2006b). In this study humans and robots play collaboratively as a team, unlike traditional human versus machine board games. They used a large checkerboard as a physical environment where humans and robots represent the game figures that play the game. Interaction methods and robot behaviours were explored and evaluated during their user study. Furthermore, remote collaboration over the internet has been studied from Reed et al. (Reed, Peshkin, Colgate, & Patton, 2004) and Monferrer and Bonyuet (Monferrer & Bonyuet, 2002) for controlling the robot collaboratively and the initial results suggested that the proposed interfaces have helped the remote interaction and also highlighted some significant factors for designing such systems. Moreover, Murphy and Burke (Murphy & Burke, 2008) discuss the possibilities of shared roles between humans and robots for collaborated tasks and the need for remote presence of humans on various applications. They explore the advantages of remote controlling and presence between humans and robots for various tasks such as one or more users cooperatively and precisely controlling robots in unsafe environments who want to project themselves through the robots for better manipulation and perception.

2.5.1 Tangible interfaces

A tangible user interface (TUI) is a user interface that allows participants to interact and feel a virtual environment by utilising physical objects. Embedding interactivity into physical objects is something that enhances the communication by using traditional toys or objects which are familiar and touchable by the users along with digital representations controllable from the same objects. This combination of physical and digital explorable worlds can add interactivity to the current communication channel in order to improve distant play and interaction especially for children (Revelle, Zuckerman, Druin, & Bolas, 2005). Researchers investigated the use of tangible interfaces in our everyday lives (Ishii & Ullmer, 1997) and also developed systems to improve child engagement in long distance communications with the help of their grandparents. "Family Story Play" allows the grandparents to read books with their grandchildren over the internet (Raffle et al., 2010). The system consists of a paper book, a video conferencing technology, a sensor-enhanced frame and a video with the character called Elmo from "Sesame Street Muppet" TV series. The results of their study indicate an increase of the quality of interaction between the children and their grandparents along with an improvement of child engagement in long-distance communications. Similarly, researchers proposed a novel concept for children-children communication with the use of toys, to control the user interface instead of a direct control from the children (Freed, Burleson, Raffle, Ballagas, & Newman, 2010). The system consists of an enhanced doll-house on each child's side along with a user interface and manipulable toys. Children use their imagination and play with the system components and share their experiences during playing. The results of this study indicate that the manipulable and toy-perspective elements can help the remote interaction and enhance games between the children. Additionally, Bonanni et al. (Bonanni, Vaucelle, Lieberman, & Zuckerman, 2006b) developed a remote collaboration system named "PlayPals" with wireless tangible figurines to allow children to play from distance and share multimedia experiences. Their system supports two or more tangible dolls which are synchronised with each other therefore interaction with one doll replicates the movements to the remote doll in the same way as locally. Furthermore, children can use various doll-sized accessories with the dolls in order to enhance their functionalities such as a walkie-talkie to enable voice communication between the children. Their short-term experiment suggested that Playpals enabled new forms of expressions as it helped the children to express their feelings and thoughts with their parents and other children much easier than they did before.

Additionally, tangible interfaces have also being used to support therapy for various diseases such as Cerebral Palsy and Li et al. (Li, Fontijn, & Markopoulos, 2008) performed a study with a table-top game in order to support the treatment of children with this disease. The researchers developed the system with the help of therapists in order to design it for appropriate interaction with the children suffering from Cerebral Palsy. Results from this experiment revealed that their proposed game enhanced children's experience and motivation for arm movement during the tangible game. The evaluation of this system showed that remote tangible interfaces have the potential to support therapy for people with various illnesses or mobility disabilities.

Lapides et al. implemented a three dimensional tangible user interface for controlling multiple robots in a building environment and compared the proposed mode with a conventional graphical interface (Lapides, Sharlin, & Costa Sousa, 2008). Their goal was to compare these two modes with 20 participants and analyse the qualitative and quantitative results. Their study included two iterations, a completely virtual environment like a traditional video game and with real robots (SONY AIBO robots) integrated into the interface. The game objective was to guide the virtual or the real robots inside the building between multiple floors and find the hidden bomb the fastest possible. Although their primary study did not determine on which mode was “better”, their qualitative results suggested that the tangible interface was more preferable to the users as they found it more intuitive and smooth than the conventional mode. Richter et al. (Richter, Thomas, Sugimoto, & Inami, 2007) proposed an evaluation system for remote tangible collaboration between two distant users. Their goal was to measure the social presence differences between a traditional operated computer with mouse and keyboard and their tangible interface for a furniture placement task. They tested the system with 20 participants and found that the tangible user interface increased the social presence and made the interaction more personal for collaboration tasks compared to the traditional user interface. A similar study was performed from Bainbridge et al.(Bainbridge, Hart, Kim, & Scassellati, 2010) where they evaluated the importance of physically present robots on a collaborative human task. Their findings conclude that participants had a more enjoyable and positive experience when interacting with a physical robot rather than with a video-displayed agent.

Based on Richter et al. Remote Active Tangible Interface (RATI), Furuhira et al. (Furuhira, Marais, & Thomas, 2008) proposed an implementation of a larger scale version of RATI with 6 tangible robots. Each robot is directly linked with the remote robot and replicates the movements on the same path on the table. The users can physically move the robots and the movement is measured through the robot's optical sensors. Various collaborative games can be supported for remote active tangible interaction as the key element for interaction is moving physical objects which are linked with digital representations on the table screen. Meppelink et al. (Meppelink & Martin, 2003) designed and developed a remote tangible interface for physical Chess playing. The proposed system allows a player to play with the computer or another user in remote location who has the same hardware. The hardware consists of a chessboard, Chess pieces, robotic arm to manipulate the pieces, an optical sensor to view the pieces position and from a computer. The system used pre-existing parts for developing thus reducing the total cost and complexity of the game interface.

2.5.2 Haptics

The above mentioned projects (Tangible interfaces) have indicated that touch can improve interactions between humans and robots, even in cases where the robot is located away from the tele-operator. Further to these projects, a much related research area is that of haptic technologies. Haptics is used in systems to provide touch feedback to the operators/users (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-de-la-Torre, 2004). Since robots could be utilised as social communication mediator tools, providing various multisensory input to the users, such robots could offer similar to the haptic device experience. Brave and Dahley (Brave & Dahley, 1997) suggested a new way of interpersonal communication that provides a physical link to distant users with the help of special haptic devices on each remote end. Their proposed haptic tool was one of the first communication tools that had the potential to enrich distant communications and provide basic guidelines for future tools with more features. Additionally, Brave et al. (Brave, Ishii, & Dahley, 1998) proposed two systems for collaborative tangible communication based on the concept idea of Synchronised Distributed Physical Objects which uses tele-manipulation technology in order to allow distance users to feel that they are interacting with the same shared objects. The first system is called PsyBench and it allows distant users to cooperatively interact with in a shared physical workspace and their presence is related to the physical objects. inTouch is a tangible telephone device that consists of three mechanical rollers on each side in order to share physical sensation over distance. inTouch transmits haptic sensation to the remote user who interacts with it on the other end. Both of these systems have formed the base for future remote tangible devices that many researchers used and still use for their experiments. Basdogan et al. (Basdogan, Ho, Srinivasan, & Slater, 2000) investigated the potential influence of haptic devices on the togetherness between the users for distant communications. Their experiment focused on two people interacting and cooperating with each other in a shared virtual environment either for performing a task of playing a game while wearing special devices to transmit and receive touch feedback with each other. Questionnaire results from their experiments suggested that haptic feedback significantly increases the sense of togetherness between the distant users. Furthermore, the degree of togetherness significantly improves the performance of the allocated task in the shared virtual environment.

Moreover, these special devices have been used on many research projects and especially on computer games (Faust & Yoo, 2006) and virtual environments (Buttolo, Oboe, & Hannaford, 1997). Until the end of the 20th century, computer games were usually limited to visual and audio perception while completely ignoring the sense of touch. Developing a computer game capable of offering haptic experience to the users and especially for people with disabilities (i.e. visual or audio impairments) can be challenging but is possible (Archambault et al., 2007). HaptiCast is a game test bed which allows users to experience the feeling of touch and increase the level of immersion and entertainment through haptic interaction and effects in 3D games (Sheldon, Mora, Jochen, & Won, 2008). In this project the users are utilising a Phantom Omni[5] haptic device to move and interact inside a 3D world. Figure 7 displays a Falcon, a cheaper alternative of Phantom Omni but with fewer capabilities and DOF. Furthermore, special wearable haptic devices

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[5] URL: http://www.sensable.com/haptic-phantom-omni.htm, last accessed July 2012

have also been used in 3D games such as in Second Life (Tsetserukou et al., 2009). The operation of these devices are very similar to Huggy Pajama (Section 2.5). However, in this project users who wear the devices play a game and sense the other user emotions which are reflected from the virtual world. In this project users have to wear a number of devices such as the HaptiHug which simulates a hug from distance, HaptiWarmer which transfers warmth to the other user, HaptiHeart which produces special heartbeat patterns according to remote user emotions and a HaptiTickler which includes vibrating motors for touch sensation. These devices operate simultaneously during the Second Life game in order to reproduce the virtual sensation to the other user. Another interesting project is the Haptic Battle Pong where two users play the traditional Pong game but this time in 3D and instead of keyboard or joystick they are utilising an Phantom Omni Haptic device to control their characters (Morris, 2004). In this project the author demonstrated that users preferred the haptic device to control the game over a conventional computer interface. Users also found the game intriguing and effective as it enhanced their sense of interaction in a two player mode compared to an ordinary computer game.

Figure 7: Falcon haptic device

The emergence of haptic devices occurred due to the need of immediate feedback from ordinary tele-operation controllers and especially for critical and hazardous scenarios such as remote handling of nuclear waste and space explorations. Additionally, tele-surgery required accurate remote controlling of various robotic platforms such as the da Vinci robot[6] which is being sufficiently controlled from Omni Phantom haptic devices. Apart from utilising haptic devices and control for remote communication between the users, haptic devices are also useful for tele-operated application such as remote controlling a robot and providing useful feedback to the operator (cf. (Takahata, Hayashi, & Furukawa, 2007)). Lee et al. (Lee, Sukhatme, Kim, & Park, 2002) have extensively used haptic feedback on their tele-operated robot in order to endow their research with information about the environment. The controlled robot was avoiding objects in semi-autonomous operation but with the help of sensory information provided to the operators it was able to avoid and turn more efficiently. The operators utilised the feedback along with the visual data from the robot and managed to achieve better performance on the task as with the aid of feedback the robot avoided more objects and kept bigger and safer distance from them. Additionally, Mitsu et al. (Mitsou, Velanas, & Tzafestas, 2006) enhanced a robot with haptic features in order to explore unknown environments more efficiently and in less time than with a robot without haptic feedback. Their experiments suggested that the enhanced version of the robot (haptic) improved the navigation time (less time) and operator perception of the environment and consequently made the navigation easier for the operators.

Touch sensation can not only be experienced through special haptic devices, but through commercial joystick interfaces too (with motor vibrators). Even with these joysticks, users can sense and visualise the virtual game structures (Johansson & Linde, 1999). The advantage of using these devices is that they cost only a fraction of a special haptic device (such as the Phantom Omni) and at the same time offer force feedback which can be used

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[6] http://www.intuitivesurgical.com/products/davinci_surgical_system/, Last accessed on 10-10-2012

to provide visual information to impaired users. However, due to the simplicity of the device, only simple representations and structures can be visualised from the users. Haptic devices influence the manner in which people interact with another remotely located user (Bailenson & Yee, 2008). Bailenson and Yee developed a test bed for haptic experiments in 3D environments by using a Phanton Omni unit as the interaction tool. In these experiments the researchers came to the conclusion that users tend to touch digital representations of the remote users in a manner consistent with experiencing high degrees of co-presence and in a parallel approach to the one that occurs in a face-to-face interaction. Even though haptic devices offer an important tangible input to the users, Kuber et al. developed a non-visual memory game in order to compare users' performance in the game by using haptic devices in conjunction with other modalities such as speech feedback (Kuber, Tretter, & Murphy, 2011). Their results revealed that users achieved higher scores when haptic feedback was presented in combination with other modalities than haptic feedback alone.

2.5.3 Telepresence and remote expressions

In face to face communications, humans can see, feel and directly interact with each other, which is something currently missing from remote communication. More specifically, seeing humans performing behaviours during the interactions is a factor that enhances the communication experience. Suzuki and Fukushima (Suzuki & Fukushima, 2008) identified that expressing bodily behaviours and feeling the presence of the remote user significantly enhances the communication. They proposed the use of robots on each communication side in order to replicate the users' expressions and furthermore increase the sense of presence. Similarly, Adalgeirsson and Breazeal (Adalgeirsson & Breazeal, 2010) developed the “MeBot” (Figure 8), which is a telepresence robot that allows the users to express non-verbal behaviours that are commonly used in face-to-face interactions. The robot consists of a small moveable body with servo operated hands that perform teleoperated gestures and movements. A small-sized screen is integrated in the robot's head and displays the other user's face. Results of user studies showed that in a comparative study, users preferred the MeBot communication over the static robot that could not move and express behaviours.

Figure 8: MeBot robot (Kuzuoka et al. 2000), image is used with permission from H. Kuzuoka

Furthermore, users found the expressive robotic embodiment more engaging and enjoyable and consequently, it was concluded that the option of remote expressiveness contributed to a better cooperation.

Similar to MeBot, but with less complicated hardware, is the "GestureMan" mobile robot (Kuzuoka et al., 2000). GestureMan was mainly developed in order to embody a remote operator's instructions by using a Pioneer base unit[7] as the mobility gear and a camera with tilt ability and a laser pointer to express and capture human behaviours. The operator controlled the robot with the help of a remote joystick and a wireless camera. With the help of GestureMan, the researchers showed that a remotely controlled robot has the ability to embody the actions of the remote instructor.

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[7] Pioneer P3-DX, http://www.mobilerobots.com/researchrobots/pioneerp3dx.aspx, Last accessed on 10-10-2012

2.6 Discussion and conclusions

Human-Robot Interaction (HRI) is advancing through the years as more and more technological achievements appear in the form of commercialised domestic robot with various user friendly capabilities that partially fulfil human expectations. A number of studies have shown that in order for a robot to "live" and interact among humans in domestic environments it should be socially accepted. For that reason, the robot's form should comply with today's trends that humans find appropriate and suitable for interaction. Furthermore, robots should initiate interactions and respond accordingly and at the same time to avoid causing frustration to the users. Moreover, various studies have shown that robots capable of perceiving and expressing emotions and suitable behaviours could enhance the relationship with humans and make it more enjoyable and creative.

Similar to HRI, humans also interact with intelligent hardware devices such as computers on a daily basis. Studies in Human-Computer Interfaces concluded that humans can form a social bond with their computers which is believed to also apply to similar hardware devices such as robots. Besides the human to computer bond, researchers have shown that computers could be used to enhance and enrich the social relationships between distant users. Computer Mediated Communications (CMC) have been used widely in many fields such as entertainment, remote teaching, collaborative tasks and many more. However, although CMC partially enhances communication in regards with visual information, it still misses an important sensory information which is touch. Touch has major implications on human communication and interaction as it provides comfort, positive social signs and immediate feedback. Numerous studies have shown that touch, even if replicated from humans or autonomously driven from the robot or special device, can enhance a distant communication. Researchers utilised special devices either worn by the users or touching them in order to simulate the distant touch (e.g. hug) on remote communication. However, although such systems enhance communication by providing the haptic sensation, they require special hardware, which may be difficult to acquire and may be unacceptable to a group of users, such as children. This could be due to the fact that most children would feel uncomfortable when wearing such hardware as it would significantly reduce their ability of free physical movement. Furthermore, in order to “sense” the distant hug, users are required to wear a particular vest continually, which might prove to be impractical or unacceptable for long-term use.

Communication enhancement projects investigate touch as a communication medium, which is a ‘missing sense’ in most current communications. Researchers have shown that touch can improve interaction between humans and robots, even when the robot is located away from a tele-operator. Furthermore, besides the sense of touch, another important factor that contributes towards communication enhancement is the sense of presence. On remote human-human communications the lack of presence could also be simulated through robots that can replicate various behaviours executed remotely. Tele-operated robots can mimic the instructor's expressions and replicate them locally for the other user to see. Telepresense and remote expressions could be utilised by domestic robots as nowadays they provide high connectivity and degree of freedom for various expressive movements.

Remote communication can be enhanced and offer unique features on both remote ends. However, current technologies and research projects are quite limited as they depend on special devices that have been exclusively developed for the specific project thus limiting their functionalities only to facilitate remote communication. On the other hand, domestic robots that operate autonomously could also be used to facilitate and enhance remote communication. Furthermore, robots can store events and remember useful communication characteristics that could be utilised in future communications in order to make human-human interaction more enjoyable and efficient.

The reviewed studies in this chapter have shown the advantages and disadvantages of human-human remote communication and various methods for enhancing it. We also listed various projects that utilised robots in domestic environments to help the users in a variety of tasks and discussed their potential in remote communication in the role of social mediators. However, as this literature review assessed, autonomous robots have never been used in remote communication enhancement scenarios therefore, our first research question sets goals for investigating robots' usage and suitability on such scenarios. Based on the argument above, we chose for our first research question:

RQ1*: Can an autonomous robot be a social mediator in human-human remote communication?*

Additionally, Computer-Mediated Communication (CMC) and haptic have shown to improve various aspects of remote human-human communication and generally enhancing the touch sensation. For that reason, in order to have comparable results from a robot mediated communication it was compulsory for us to compare our results with a similar system that lacks robot interactivity and utilises conventional computer devices as an alternative medium of interaction. Our second research question focuses on comparative studies between those two interaction modes in facilitating users' remote communication and more specifically is shaped as follows:

RQ2: *How does an autonomous robotic mediator compare to a conventional computer interface in facilitating users' remote communication?*

Finally, some of the reviewed projects utilised various special hardware devices to enhance human-robot and human-human interaction that required a new methodological approach for analysing and interpreting the results. In our scenario where robots operate as intelligent and autonomous social mediators on remote human-human communication, it was necessary to employ a different methodology in order to understand and analyse the resulted qualitative and quantitative data from the studies. Our third and final research question focuses on finding appropriate and repeatable methods for extensive and reliable data analysis. Based on this argument, we formed our third research question as follows:

RQ3: *Which methodology should be used for qualitative and quantitative measurements for local user-robot and user-user social remote interactions?*

Chapter 3: Designing a social mediator

Chapter 1 introduced the term “social mediator” and illustrated how robots could be utilised as such in order to enhance a remote communication. This chapter will list and analyse the requirements for the robot and generally for the system, as well as hardware characteristics of the chosen platform and software. Furthermore, it will analyse the software implementation from the physical robotic perspective along with the communication software (computer interface). Finally, it will describe the evaluation and modifications that took place in order to improve any imperfections and adjust the software parameters for a more natural and constructive human-robot interaction.

3.1 Introduction

Human-human remote communication can be established either via ordinary phones or computer devices. In Chapter 1 we analysed the importance of touch in remote communication and how it could be enhanced with the use of robots. Chapter 2 listed and described various methods used for communication enhancement in similar projects. Namely, most of them utilised special hardware devices for touch mediation while some other used robots. However, none of them exploited autonomous robots that could run independently without the help of a computer. We define a robot as being autonomous, a device that can run and execute behaviours independently as well as reacting to its environment in real time without any user intervention. This PhD focuses on socially interactive robots as mediators in human-human remote communication. We decided to use autonomous robots placed next to the participant’s computer who uses a tele-conference application to communicate with the remote participant. In order for a robot to be utilised as social mediator it should be suitable for the experiment. In particular, we reviewed various domestic robots like AIBO, NAO, PLEO which are small in size while they are still affordable and available to find (AIBO only as a second hand product as production seized) although the proposed platforms of this study have the potential to move to other devices as well due to its expandable architecture (see appendix V). After reviews and investigation we adjudicated to use AIBO ERS7 series robots since they fulfilled our requirements for the robot role as social mediator (see Robot Specifications in section 3.2).

The remote communication platform that we designed consists of two AIBO robots, two personal computers, two wireless routers and two web cameras. Figure 9 illustrates the platform setup and the connections between the objects.

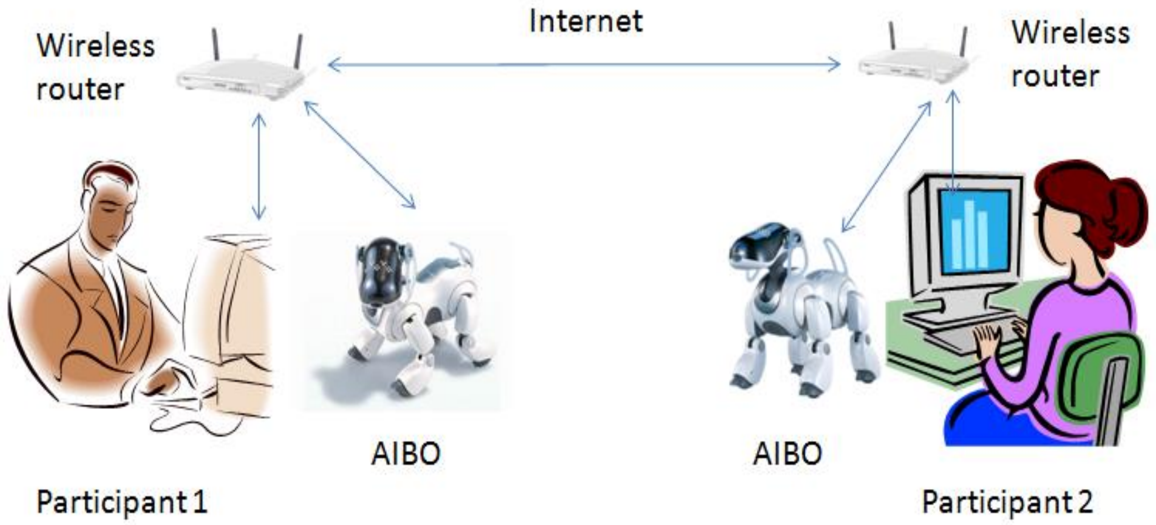

Figure 9: System setup

The system that we propose and later build, allows each user to physically interact with the AIBO robot while they communicate with the remote user using a video conference application (e.g. Skype). The robots are wirelessly connected to the computers in order to interact with our software which operates as an enhanced computer interface for the users. The software that sits on the computers, allows the users to interact with each other with the help of a collaborative task. In order to engage the users we decided to use collaborative games that employ the AIBO robots as physical interactive devices for the role of social mediator. Collaborative games deliver enjoyable experiences to the users and if designed properly can be engaging and rewarding. Additionally, we chose to use robots in conjunction with computer games since studies have shown that users prefer to interact with a real robot rather than virtual characters on the computer screen (Kidd, 2003).

A computer game was used for the user to user interaction because:

- Multi-player games offer enjoyment and collaboration for both users
- It is a real time multi-goal system
- It can be expanded easily
- It supports various modes of operation and functionalities of the robots in our experiments
- The concept can be easily understood and is familiar to most of the users

Users can play it simply by running the software alongside normal voice and video communication between the users.

Furthermore, we believe that users would express social signs in their interaction with the robots when they collaborate in their remote communication games as they do with sociable robots (Breazeal, 2002). Breazeal identified four different human-robot interaction modes which were divided into the following classes: socially evocative, socially communicative, socially responsive and sociable. The social game that we propose along with the robots, can evoke, communicate, provide a social response and be a sociable entity. This PhD research included the design and implementation of three different remote communication enhancement platforms where each one was developed specifically to answer the research questions and to explore additional issues that arose during the evaluation phase.

Below there is a brief description for each system:

3.1.1 AIBOcom

AIBOcom is a collaborative game that involved a computer game interface and an autonomous AIBO robot linked together in order to allow users to control the virtual character. In this game, both users were navigating a virtual character in the computer interface towards the exit of a virtual maze. The guidance was achieved with the help of the AIBO robot and a provided small pink ball. The user was required to move the ball in front of the AIBO's camera and the robot was following the ball forcing the virtual character to move inside the maze correspondingly. AIBO robots were running in autonomous mode executing various dog-like behaviours based on their multiple internal drives.

3.1.2 AiBone

AiBone is a collaborative game that users had to cooperate in order to find some hidden objects for each one of the five levels of the game. Collaboration benefitted both users as the game rewarded them with more points for each hidden object they would find together. Robots run in autonomous mode performing various behaviours based on their internal states and at the same time users can utilise them to guide their virtual characters inside the virtual levels. This study also included a conventional input mode to control the virtual characters in order to compare and evaluate the robotic social mediator effectiveness in the communication in terms of exhibited social cues between the users and generally value their overall preference.

3.1.3 AIBOStory

AIBOStory is a non-task oriented communication system that allows the users to share stories from distance. In this system, the AIBOs run in autonomous mode executing various dog-like behaviours while at the same time the robots could contribute to the written story based on their internal states. The internal states are directly linked with the user's interaction and therefore, this interaction will be imprinted to the story as written elements. In this system, users can select various story elements from the interface list or write their own. The story is written in turns unless a robot contributes autonomously. Most of the story elements are directly linked to the AIBOs and thus, they can trigger various predefined behaviours. In this platform, the robots are running in 'mirroring' mode therefore, each local behaviour is being copied to the remote robot along with the internal states. Additionally, AIBOs have an embedded memory algorithm that stores each user's previous selections and choices and offers them discreetly to the users as suggestions for their next choice. AIBOStory is intended for long-term interactions as it can store users' preferences and utilise them for future interactions.

AIBOcom, AiBone and AIBOStory were designed based on our requirements for a remote communication system utilising robots as social mediators. Below we will analyse the requirements and specifications for the robot and the software that sits on the computer.

3.2 Robot specifications

As described in the previous sections, the role of a communication social mediator robot had to fulfil various requirements in order to fit into our communication system. A robot companion must be able to perform multiple autonomous behaviours and for that reason, acquiring a fully autonomous robot that could run embedded code independently was our first requirement. Additionally, we wanted the robot to be able to interact with the users and the environment therefore, various touch sensors and camera module were mandatory for our system. Furthermore, we expected from a robot to perform a range of expressive behaviours. Consequently, a high degree of freedom and multiple lights for mood expression were desirable. Moreover, since our communication platform involved two robots and computers, we anticipated a wireless connectivity from the robot in order to synchronise the data with the other robot and the computer. Lastly, we required a robot that is commercially available to the public and relatively cheap in order to make our system available to the wider public for domestic environments.

Based on the requirements above, we selected the AIBO ERS7 model to serve the role of the social mediator in our communication system(Fujita & Kitano, 1998a). We used Sony’s AIBO ERS7 for the role of the robot because of its advanced technology, pet-like appearance and positive acceptability by users (Bartneck et al., 2006). Previous research in this domain (see Section 2.2) revealed that various hardware devices able to perceive and transmit touch sensation remotely can enhance the remote communication. However, most of these remote communication enhancement projects use special hardware devices that are specifically built for this application, which subsequently reduces the ability for flexible and immediate communication in domestic environments, as these special devices are usually expensive, difficult to develop and unreliable. Furthermore, another important factor that could potentially limit their usage is the questionable acceptance of users – when humans are given unfamiliar hardware, they usually need a lot of time in order to accept and learn how to operate this new equipment. This was the primary reason why we chose the AIBO robot as the hardware device for our communication system. Furthermore, the AIBO robot has an embedded CPU and RAM, which allows us to execute code on the hardware level and make it completely autonomous.

The AIBO robots have been widely used in the research community as they offer multiple sensors, high degree of freedom in their movements and an independent processing unit capable even for image and voice recognition. AIBO robots have been used in numerous studies such as companion robots (Calvo, Datcu, & Rothkrantz, 2007), watchdog for home surveillance (Yang, Hau, & Rothkrantz, 2006) and soccer and rescue game player (Datcu, Richert, Roberti, De Vries, & Rothkrantz, 2004). Additionally, researchers have used AIBO robots in order to develop and imitate real animal behaviours and allow it to learn new skills (Austermann & Yamada, 2008; Kaplan, Oudeyer, Kubinyi, & Miklósi, 2002; Seiji & Tomohiro, 2004; Soni & Singh, 2006). Similarly, various studies with AIBO robots included modelling of new personalities and decision making architectures with positive results (Arkin, Fujita, Takagi, & Hasegawa, 2001; Dobai, Rothkrantz, & van der Mast, 2005; Yang & Rothkrantz, 2005). Moreover, AIBO robots have been used to understand the verbal interaction between robots and humans (Kaplan, 2000) and social implications of the origin of the language (Steels & Kaplan, 2001). Human-robot interaction with AIBO robots inspired researchers to perform various studies in an attempt to investigate the quality of the interaction and the benefits (Jones & Deeming, 2007; Kubinyi et al., 2004; Tejada, 2008). Furthermore, Friedman et al. stress the acceptance of AIBO robots in everyday life activities based on the analysis of discussion forum messages (Friedman, Kahn, & Hagman, 2003).

AIBO robots have been used in multiple studies and has proven its capabilities even for difficult autonomous tasks (Rico, González-Careaga, Plaza, & Olivera, 2004) like the Robotcup[8] official tournament. In this cup, multiple AIBO's had to coordinate autonomously in order to win the game against the opponent group of AIBO's. As indicated above, in order for the robot to interact with its environment it needs a body

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[8] URL: http://www.robocup.org, last accessed July 2012

capable of performing gestures and facial expressions. Additionally, the expressed behaviours should be understandable from the user. Therefore, the robot's hardware should allow for smooth programmable movements for positive user believability (Bursie, 2004). The AIBO's hardware fulfils our requirements for autonomy, social cues including expressive behaviours, intractability, wireless connectivity and availability. AIBO is equipped with several sensors on its body which are using two different technologies, electrostatic and pressure type (Bie & Persson, 2004).

Figure 10 synoptically illustrates the characteristics of the AIBO ERS7 model.

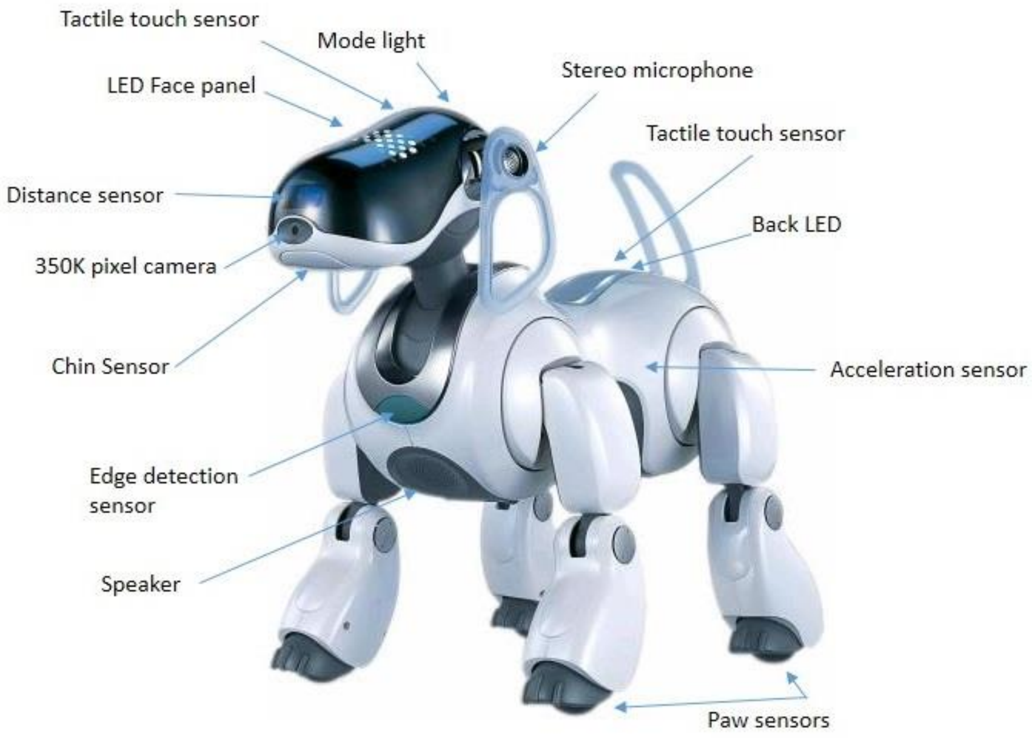


Figure10: AIBO features

There are three electrostatic sensors on its back and one on its head. These sensors can decode the touch pressure into 35 district values. Additionally, each petting is being represented through LED lights on its surface that lights correspondingly with the touch pressure. The pressure sensors are located under each paw and the chin, which only serve as on/off switches. The paw sensors are being used for balancing, walking and generally detecting if there is an obstacle under each leg. Similarly, the chin sensor can be used either for petting or for identifying an obstacle prior opening the mouth. With these sensors, the AIBO robot can perceive user's physical input and its environment. AIBO is also equipped with two microphones, one in each ear, giving it the ability to understand the source of the sound thus turning the head correspondingly. The head contains a small low resolution (350K) colour camera that is used for visualising and two infrared sensors for distance measuring. It utilises a combination of two sensors for maximum resolution, as one provides information for objects near the sensor and the other for far. Similarly, its chest is equipped with a long range infrared distance sensors for detecting objects, edges or cliffs. Internally, AIBO is supplied with 3-axis accelerometer sensors for detecting movement and temperature sensors for the ambient temperature. An embedded IEEE 802.11b wireless card provides AIBO with connectivity with computers, wireless routers and other sources. The head consists of a LED panel capable of illuminating the lights separately and in different colours (white, green, red and blue) for producing various emotions. AIBO can produce polyphonic sounds through a small speaker on its chest. AIBO is a well performing four-legged robot capable of expressing multiple behaviours smoothly and quickly. The movements are achieved through 17 stepper motors in AIBO's joints, equipping it with a high degree of freedom. Each motor can also detect force feedback in order to detect if any of the planned movements are obstructed by any objects or the user.

3.3 Software specification

In order to develop a novel communication platform with the requirements described in the first section, we needed to find a suitable programming language that supports communication between the computer and the AIBO robots along with any networking capabilities required for synchronising the distant computers. We decided to use three different programming languages as each part of the system required a different approach. As it can be seen in Figure 9, the system consists of an AIBO robot, a wireless router and a computer. For that reason, the AIBO robot was programmed with a universal robotic language that supports multiple platforms including the AIBO, called URBI (Baillie, 2004). This language runs in server-client mode where the server sits on the robot side and the client sits on the computer. AIBO has been programmed in such a way as to run autonomously but at the same time to communicate with the computer (server) and execute various predefined routines. The client side of URBI is running on the computer a separate DLL library that handles the communication between the AIBO and the computer application. This DLL file had to be written in C++ as it handles low level communication commands. Both the client and the server code could be reused for future scenarios as they are usable from any compatible software that supports DLL files. Those two files have been used in AIBOcom, AiBone and AIBOStory with some small changes to adapt on each version. Each communication platform had a different interface module that defined the communication and interaction between the distant users. The interface has been written in Visual Basic language as it provided rapid development with graphical interfaces and DLL support. The interface handles the communication between the distant users, synchronises the robots and the interaction and offers a visual task to the users. Visual basic supports network services as well as the TCP/IP protocol that has been used for all three platforms. Namely, we decided to use this protocol instead of UDP, because it offers higher packet reliability, data flow control and error checking (Giannoulis et al., 2009).

3.4 Implementation

As described above, the systems consist of three different modules, the AIBO robot, the DLL linker and the interface application. The reason behind our decision to divide the system into three different modules was that we wanted it to run on various platforms (Linux, Mac, Windows etc.) and to be able to modify the interface application without modifying the low level modules that control the robot's functions at the same time. The interfaces were written in Microsoft's Visual Basic 6.0 version for rapid development with embedded graphical components for games design. Our three implementations were developed for the windows platform but the linker file (DLL) could be compiled for other platforms as well (following some small modifications).

3.4.1 AIBOcom platform

AIBOcom controls two AIBOs, each interacting with a remote user, providing the ability to play a 2-player game via the AIBOs. The purpose of the game is to guide a virtual character in a computer maze by using the AIBO as an interaction tool through moving a toy object (i.e. AIBO's pink ball) in front of AIBO (see section 3.4.1.2 for a detailed mapping head movement). Each robot is an autonomous system with its own set of behaviours, sensing abilities, and internal variables and the user is expected to interact with the AIBO like a real pet in order to cope with these dynamic changes. In order to complete the game, both users have to co-operate by using voice and body gesture, and by interacting with their robots. This co-operation is essential since each AIBO affects the other AIBO's internal states at every interaction and time step.

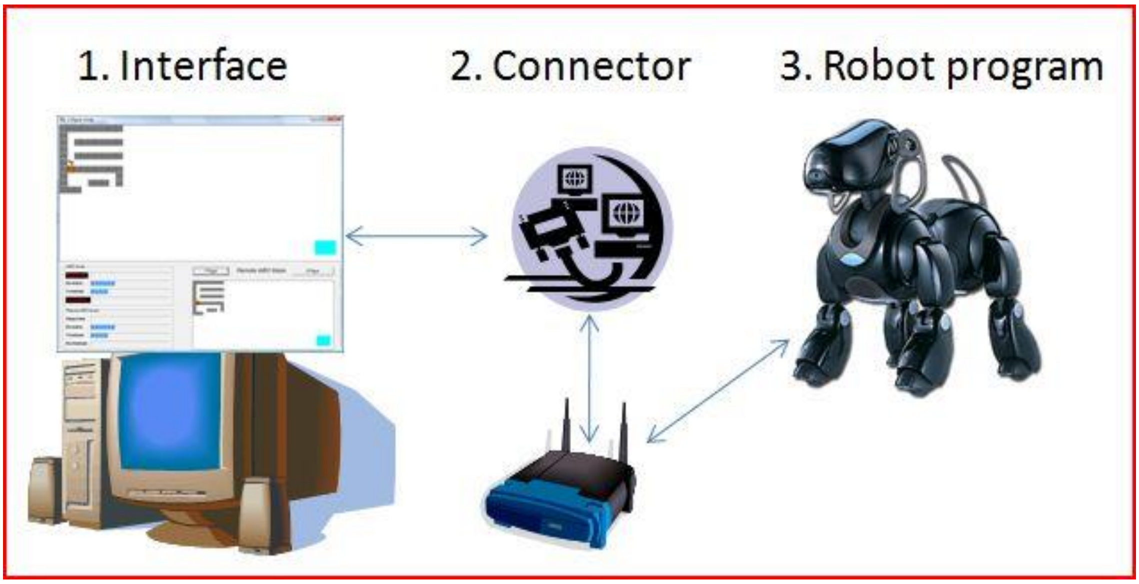


Figure 11: AIBOcom platform

Figure 11 illustrates AIBOcom's components required from each user to interact with a distant user.

3.4.1.1 AIBOcom's interface

The Interface (Figure 12) is a computer application that users interact with as it controls the network connection between the users and robots and manages the game. The interface application handles all the required network connections between the two distant users through the TCP/IP protocol. The interface includes a maze game, the main goal of which is to guide a virtual character to the exit of the maze with the help and cooperation of the remote user. The main control is a pink ball that is being moved in front of the AIBO's visual field. The AIBO robot moves its head to follow the ball, and the virtual character on screen moves horizontally or vertically inside the maze accordingly. Therefore, AIBO's vertical head movements are mapped to vertical movement of the virtual character and horizontal head movements to horizontal movement of the character (see next section for complete mapping formula). The user on the remote side also controls his own virtual character and the maze includes locked doors which require users' cooperation to open.

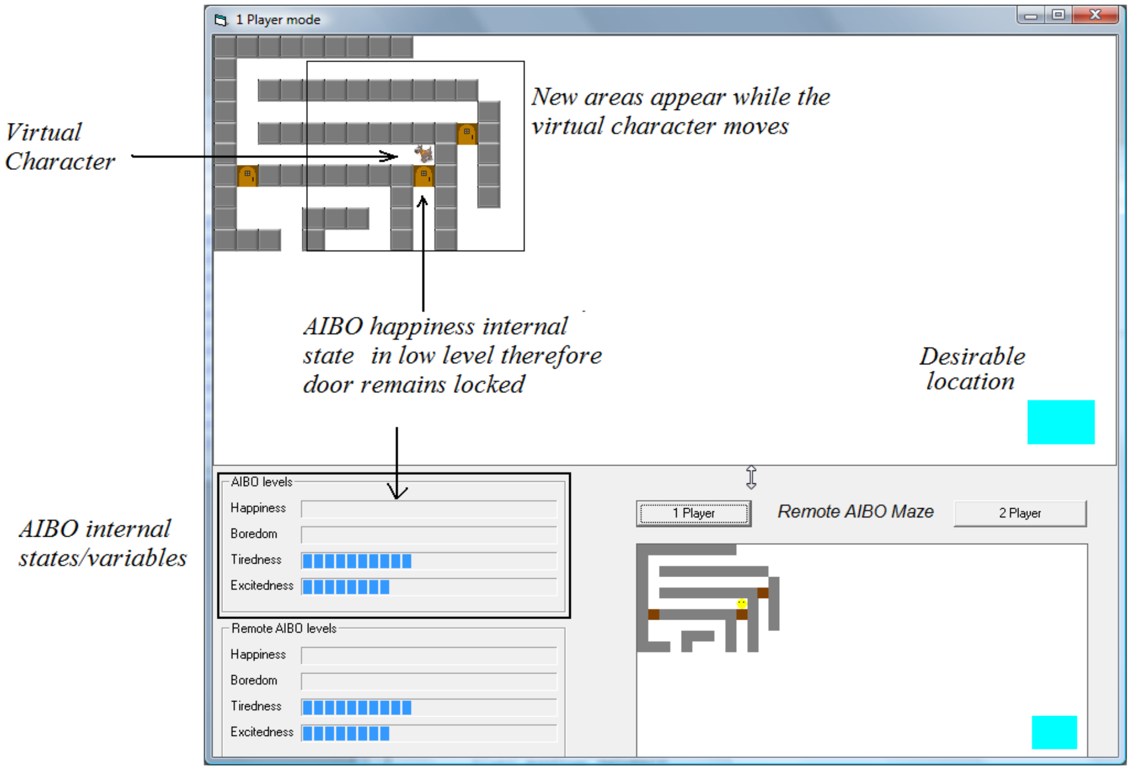


Figure 12: AIBOcom's interface

Once the connection between two interfaces is initiated, they exchange information about their local AIBO and their game state. AIBOcom utilises a two player collaborative game that offers two different game modes to the users. AIBOcom offered the 'affecting' and 'mirroring' mode which affected the way the users played the game and how the robots were synchronised. The 'affecting' mode allowed the users to play with their individual virtual characters on the screen while in the 'mirroring' mode users could only see one virtual character controllable from both users with their values averaged. A more detailed description about the playing modes can be found in Chapter 4.

The maze game consists of a partially hidden maze in which the users have to find the way to the water location (Figure 12 bottom right). The hidden walls and doors will be shown as the user moves the virtual character in new areas. Depending on which mode the users have selected, the game interface transmits data to the Linker and the remote interface differently. In affecting mode, the interface retrieves the internal states from the local AIBO robot, updates the current values on the interface and then sends them to the remote user. Additionally, it transmits the current location of the virtual character on the map. On the other end, the interface receives the data of the internal states, displays them on the bottom bars on the interface and also, updates the current location of the remote virtual character on the mini map (bottom right of Figure 12). The locked doors will open only if both remote and local virtual characters are standing behind the same doors and satisfy the requirements of happiness and excitement values. Furthermore, a virtual character will not be able to move if the tiredness and boredom levels are too low. Another characteristic of the 'affecting' mode is when a robot behaviour is triggered, the interface updates the remote client and depending which behaviour has been chosen the related remote internal states will be positively affected. On the other hand, the 'mirroring' mode utilises only one virtual character on the interface screen where both users have the control. In this mode, a local user controls the virtual character with the AIBO, but the movement will initiate only when the remote user send's his desired direction. There are 16 possible combinations of local versus remote user desirable directions as it can be seen in Table 1.

Local	Remote	Final
Up	Down	No move
Up	Up	Goes up two blocks
Up	Left	Goes up and then left
Up	Right	Goes up and then right
Down	Up	No move
Down	Down	Goes down two blocks
Down	Left	Goes down and then left
Down	Right	Goes down and then right
Left	Up	Goes left and then up
Left	Down	Goes left and then down
Left	Left	Goes left two blocks
Left	Right	No move
Right	Up	Goes right and then up
Right	Down	Goes right and then down
Right	Left	No move
Right	Right	Goes right two blocks

Table 1: User directions combinations

When one user pauses from controlling the character, the other user will continue to guide the character but without the additional speed and support of the coordinated guidance and with a slower rate of robot's internal state adjustments. In 'mirroring' mode, both local and remote AIBOs share common internal states values and execute the same behaviours simultaneously. Every 500ms, the interfaces exchange their local internal states values (happiness, excited, boredom and tiredness) and average them in order to create a common value for both interfaces. After each successful exchange, both interfaces update the AIBO's internal states and execute a selected predefined behaviour if the levels reach a certain threshold.

In addition to the visible information on the screen, the interface is also responsible for storing descriptive data every 1 second as log files. These data contain virtually everything that occurs on the interface such as the current position of the local and remote virtual characters, the active playing mode and the internal states for both local and remote AIBOs.

3.4.1.2 Linker

The Linker handles all the incoming information from the Interface, interprets and sends it to the AIBO robot. It is the link between these two components and it is specific for each robot type. The Linker program was written in C++ and compiled as a DLL library file. More specifically, in this version the Linker reads the AIBO's head tilt and pan values every 100ms and then it calculates the desired direction based on both values. Besides the desired direction which consists of one or two values (tilt and pan), it also calculates the intensity which is calculated from the derived values. For example, if the head is rotated 90 degrees left and 20 degrees down then the calculated desired direction would be left x2 and down x1. Figure 13 shows the AIBO head mapping to virtual character movements. The tilt and pan sensors of the AIBO's head have a minimum and a maximum value of -40 and +40 respectively. We mapped these sensors values into a 2D matrix which returns the appropriate virtual character movements to the system depending on the head orientation. Each dashed rectangular shape defines an area on how fast the virtual character should move. The rectangle in the centre is the idle area with tin and pan sensors less than 10 where although the AIBO moves the head, the virtual character remains in the same position. We used the -10 and +10 values in order to avoid any unwanted virtual character movements when a user wishes to remain in the same position in the virtual maze. The second rectangle with values from -25 until -10 and 10 until 25 moves the virtual character one game block per time. An example of such movement can be visualised with the help of the circle on the top left corner. In this scenario the user wishes to move his virtual character up and left. The mapping formula will translate this movement to one block up and one block left. The third rectangle with values from -35 until -25 and 25 until 35 moves the virtual character two blocks per time. An example of this 'fast' movement can be seen with the help of the top right circle where the user desires to move his virtual character up and right. Since the circle is located within the third rectangle but within the limits of the second rectangle in the x axis, the virtual character will move two blocks up and one block right. Every head movement outside the third rectangle will have the same effect on the virtual character as previously but will also cause the AIBO to perform an adjustment behaviour in order to set the appropriate proxemics with the user. In this case, if a user moves the ball extremely to the right or left, the AIBO will physically rotate towards that direction and at the same time the virtual character will move accordingly. If the user moves the ball extremely upwards or downwards, the AIBO will move backwards of forwards respectively. These AIBO orientation and proxemics adjustments are only active in the AiBone study. The interface uses these data to move the virtual character in slow (one block per second) or fast (two blocks per second) pace. Additionally, it can execute functions on the robot side on interface request such as predefined behaviours or hardware checks. Finally, it provides to the interface the current internal state values and the behaviour status in order to identify if currently the robot is performing an action.

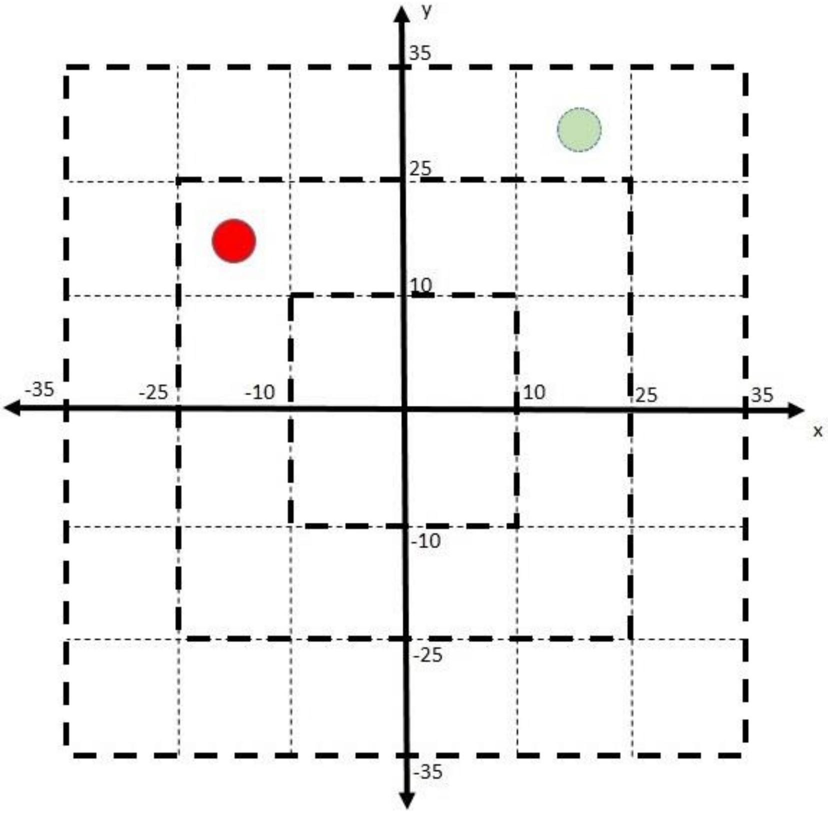


Figure 13: AIBO Head movement mapping

3.4.1.3 AIBO

The AIBO software was written in URBI language which is a universal robotic programming language that supports multiple platforms such as NAO, AIBO (all models), PLEO and many more. The programme was stored in AIBO's memory stick on top of the URBI server which controls the hardware and the software parts. On every robot boot, the URBI server takes control of the hardware and utilises the wireless card of the AIBO in order to activate it and set it up in 'Listen' mode. After the utilisation, the server waits for TCP/IP connections on address 192.168.1.199 and on port 49000. URBI server accepts peer-to-peer connections directly from a computer equipped with a wireless card and also server-to-client connections through a wireless router. We preferred to use a wireless router instead of direct connections in order to minimise the number of additional hardware in case that multiple robots were used and in order to allow laptops to connect with them wirelessly without losing the ability to have internet access (laptops are equipped with one wireless card). After the server finishes the utilisation, it automatically loads our AIBO source code and waits for clients to connect.

On client's connection, the client (interface through the Linker library) and the server exchange and synchronise various information such as internal state values, timers for the log files and execute the initial start-up behaviour (stretching and standing up). This behaviour also initiates the robot's lights in order to show to the users that the robot is active and ready for interaction. The initialisation starts the internal counters and the robot is now running in autonomous mode. The internal states will start changing and when they reach a certain predefined threshold value AIBO will automatically execute a related behaviour.

AIBO uses four different internal states to perform the behaviours which are:

Tiredness: Threshold level=60

Excited: Threshold level =30

Friendliness: Threshold level =30

Boredom: Threshold level =40

We ended up using these thresholds after a prolonged period of pilot trials with various participants in order for the robot to have an as much as possible dog-like behaviour and at the same time to avoid causing frustration to the users while they are playing the game.

Each active behaviour affects the internal states differently, for example a tiredness behaviour will keep increasing the related internal state until the active behaviour completes. The internal states are connected directly with AIBO’s touch sensors (Figure 14), therefore each user’s petting will increase/decrease the values. The head and the back sensors can measure the pressure of each petting so we utilised this feature to affect the internal states differently. We used a sensing formula to identify the pressure of the user’s touch and divided the sensing spectrum into three categories: light touch, normal touch and heavy touch (Figure 14).

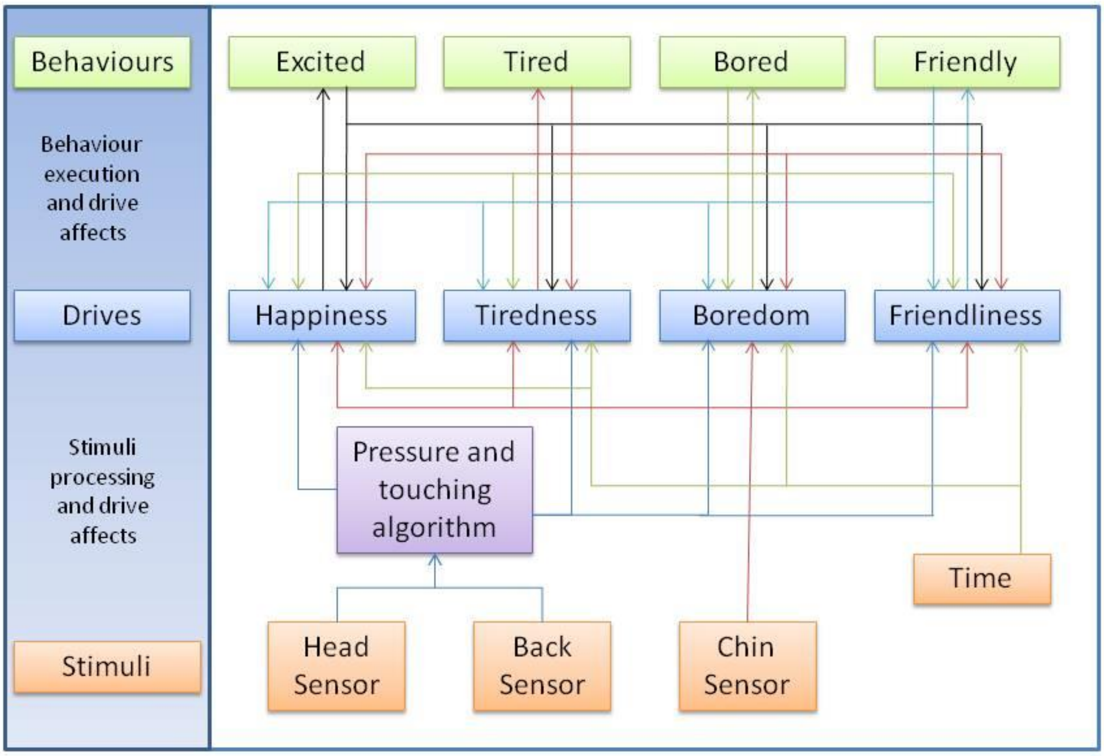


Figure 14: AIBO petting architecture

This sensing formula allows the AIBO robots to adapt to the users’ petting pressure by storing previous interactions and calculating a ‘normal’ touch value and comparing this value with any active petting. If the current petting value falls into the region of normal petting, then the algorithm will assign the current petting a positive value to affect the internal states and at the same time it will use it to update the average stored value. Similarly, a light or heavy future petting will fall outside the ‘normal’ petting region therefore, the assigned value would be a negative one thus affecting the internal states negatively.

$$N = \frac{p_1 + p_2 + \cdots + p_t}{t}$$

$$N_1 = N-4$$

$$N_2 = N+4$$

Averaging formula

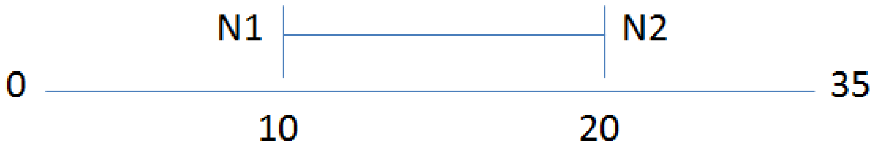


Figure 15: Sensor regions based on average value N

The average petting is calculated using the formula in Figure 15 where *N* is the calculated average value, *p* is the current petting value and *t* is the number of petting. The resulted *N* value is further used to calculate the upper and lower margins that define the ‘normal’ petting region. Initially, the *N* value is set to 15 which places the boundaries to 10 and 20 for the ‘normal’ petting region. This formula uses the default N1 and N2 values for each game session as the values are stored to AIBO’s RAM. Therefore, each new interaction with the AIBO adjusts the N1 and N2 values to personalise the petting for short-term Human-Robot adapted interaction. Upon multiple interactions, this petting region will be moved towards to user’s pressure preference providing a more accurate feedback to the system and the user. Figure 16 displays the petting algorithm in steps.

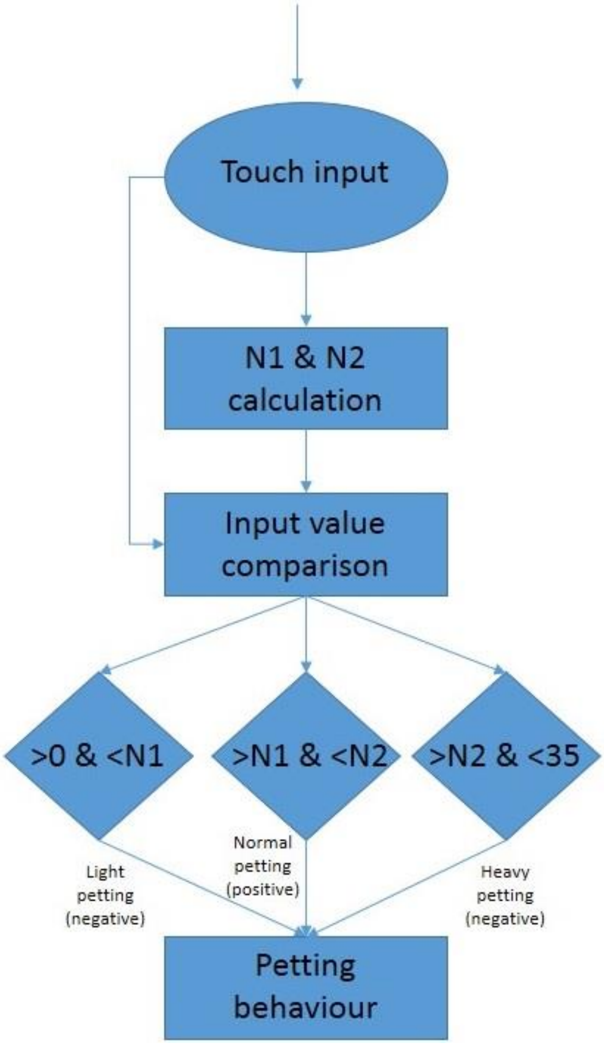


Figure 16: Petting Algorithm

We implemented several dog-like behaviours for the AIBO such as tiredness, happiness, excitement, boredom, ending and ball tracking. These behaviours will be triggered either by the internal states of the robot (threshold values) or by the interface as a consequence of a mirrored behaviour. Each behaviour activates the actuators, speaker and LED lights in a specific order enabling the robot to perform the selected behaviour as realistic as possible. Designing behaviours on a four-legged robot requires fundamental understanding of physics and balancing; otherwise the behaviours will look unnatural and actuators might get damaged from excessive force. The behaviours have been evaluated from multiple participants and later from personal communication with Dr. Ádám Miklósi who is expert on human-animal interaction. This valuable feedback was used for enhancing the behaviours with additional barking sounds and faster and also smoother movements. AIBO can only execute one behaviour at a time to avoid damage to the actuators as the robot can easily lose balance and fall. Additionally, before each behaviour the AIBO robot checks for its current body posture and adjusts accordingly to perform the newly selected behaviour. For example if the previous behaviour finished with the AIBO laying down and the selected behaviour is happiness, the algorithm will detect this posture and will firstly execute the stand-up function and then perform the happiness behaviour. Additionally, we implemented an ending behaviour to finalise the game and shutdown the AIBOs safely. This behaviour is being triggered directly from the interface and executes a happy dance as a reward to the users when they reach the end of the virtual maze. The behaviour ends with a laying down gesture following a shutdown routine which powers off both AIBOs in a safe posture.

Finally, we implemented a ball tracking function to allow the user to control the virtual character through the AIBO by using a pink ball as a tracking object. AIBO has an embedded camera in front of its head and we use a simple image recognition algorithm to detect the position of the pink ball. The algorithm detects the location of the ball and moves the head accordingly in order to position the ball in the centre of its vision. We also implemented a ball search function in case the robot's camera cannot locate the pink ball. This search function moves the head in a helical pattern in order to search various areas in its environment until it finds the pink ball. The search function influences the internal states values by increasing the boredom level and decreasing the happiness level.

3.4.2 AiBone platform

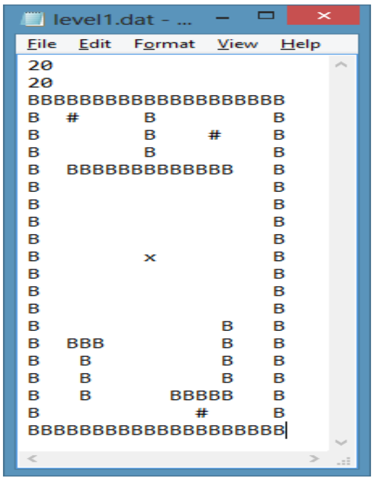
For our second study (AiBone – Figure 19) we wanted to compare and evaluate the importance of robots as social mediators in the communication. For that reason, we developed a new collaborative game (interface module) that offered two different playing modes to the users, a robot controlled and a non-robot controlled. In the non-robot mode, users utilised the keyboard and the mouse to control the virtual game character while in robot mode users had to use the AIBO robots. In this game, participants were required to guide their virtual characters through various game levels in order to find randomly hidden rewards using the AIBOs or the keyboards as interaction tools. During the game, the AIBOs autonomously execute dog-like behaviours driven by the robot's internal variables. The game offers to the participants the option to co-operate and receive double points for each hidden bone they find, or they can search for them individually, either by negotiating to split the area among themselves or by searching randomly and autonomously (applicable on both modes).

Similarly to AIBOcom, AiBone consists of the interface, the Linker and the robot program (Figure 17).

Figure 17: AiBone platform

3.4.2.1 Interface

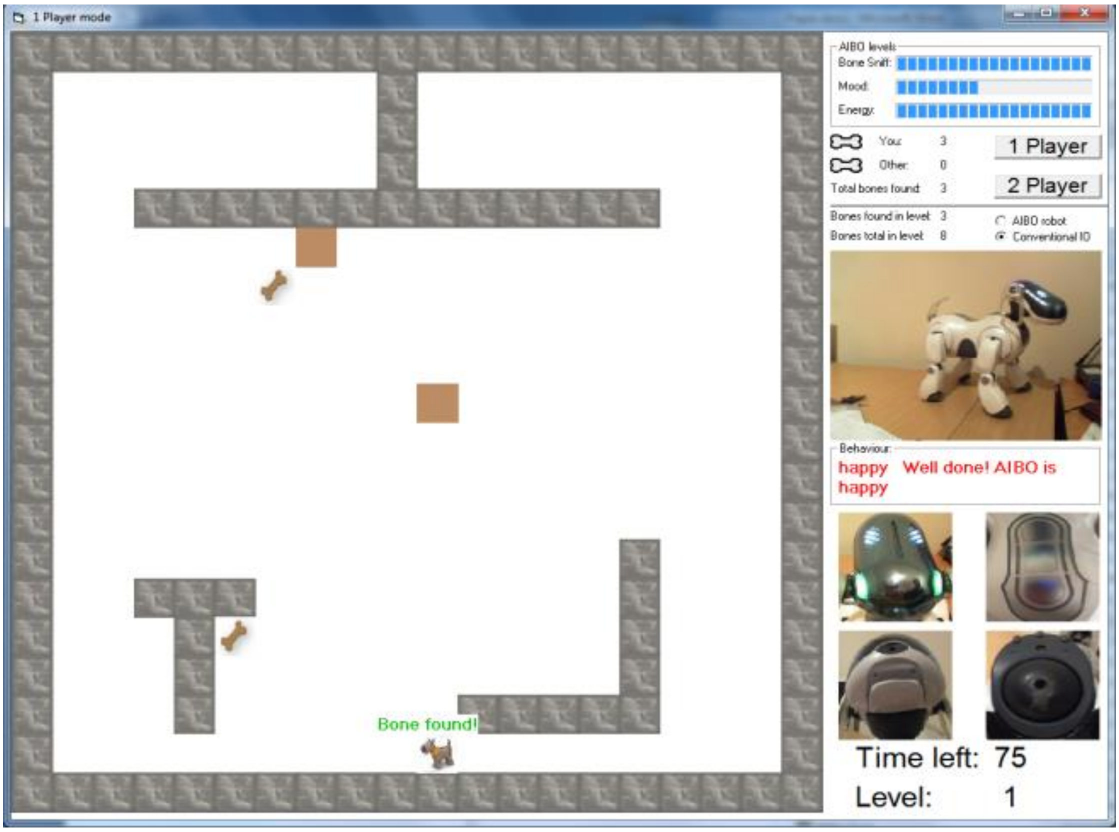
We decided to develop a game interface to enable us to load various game levels from external map files (Figure 18) without having to edit the source code of our application for new levels. With this game engine, someone could easily design new levels for the game without any programming knowledge and effort by using a simple text editor such as the notepad.



```
20
20
BBBBBBBBBBBBBBBBBBBB
B  #     B         B
B        B    #    B
B        B         B
B  BBBBBBBBBBBBB   B
B                  B
B                  B
B                  B
B                  B
B        x         B
B                  B
B                  B
B                  B
B              B   B
B  BBB         B   B
B   B          B   B
B   B          B   B
B   B      BBBBB   B
B            #     B
BBBBBBBBBBBBBBBBBBBB
```

Figure 18: Map editor

The first two lines of the map declare the number of rows and columns the level is expected to have. The B letter indicates a solid wall that virtual character can collide with while the X sets the starting point of the character when the levels loads. Finally, the # symbol represents the hidden objects within the levels.



Bone found!

You: 3
Other: 0
Total bones found: 3
Bones found in level: 3
Bones total in level: 8

happy Well done! AIBO is happy

Time left: 75
Level: 1

Figure 19: AiBone interface

Figure 19 displays the generated level of Figure 18 loaded map file. AiBone interface handles the network communication between the remote users by utilising the TCP/IP protocol in the same way as AIBOcom. Once the connection is established between the two users, the interfaces exchange synchronisation data regarding robot's internal states and game status. The interface comprises multiple components with the level representation occupying the biggest part. The interface displays vital information to the user regarding his progress in the game and various internal states from the AIBO such as its mood and energy states. The purpose of the game is to find as many hidden bones as possible in the provided levels. For that reason we implemented a progression bar called ‘sniffing’ to help the users locate the bones faster and more efficiently. Since the bones are hidden on various random blocks within each level, a user utilises this sniffing bar to apprehend whether he is approaching the hidden bone. The ‘sniffing’ bar indicates with 4 different values the distance of the virtual character to the bone. On every character movement, the game analyses the surrounding 64 blocks of the character for hidden bones and represents this distance with a value on the progression bar. Every time a user wishes to collect a bone, he has to initiate the digging behaviour in order to extract it. If the virtual character is standing on top of the bone then the player will be rewarded with one point and the character’s energy internal state will be increased along its mood.

The game interface offers two playing modes as described above, a conventional mode where the player utilises the keyboard and the mouse to navigate the character and the robot mode where AIBO robots replace the conventional devices for navigation and interaction. For the conventional mode we developed a graphical representation of AIBO’s behaviours and interaction sensors in order to replicate the real AIBO as close as possible to reduce cognitive effects for the users. We captured all of the AIBO’s basic behaviours with multiple static images which are displayed as video animation to the user similarly to a real AIBO. In the robot mode, the internal states are synchronised every 500ms between the interfaces and the AIBO robots receive an average value from the two users. In AiBone we decided to combine the happiness, excited and boredom internal states into a multiple stage one called Mood. The Mood internal state is a continuous progression bar divided into three sections where the values from 0 to 33 indicate the region of a boredom mood, 34 to 66 a happiness mood and everything above 66 an excitement mood. A detailed description on how the modes affect the user-user interaction and robot synchronisation can be found in Chapter 5.

3.4.2.2 Linker

In AIBOcom subsection we described the Linker module and its compatibility with multiple version of interfaces. For AiBone, we utilised the same Linker with minor additions to it such as the extra dog-like behaviour routines and several AIBOs to interface synchronisation variables. Even after these new additions the Linker is still operational and compatible on older platforms.

3.4.2.3 AIBO

The AIBO software mainly consisted from parts of our AIBOcom platform with several additions such as new behaviours, tracking routines and logging capabilities. The previous AIBOcom platform included multiple dog-like behaviours that were utilised for AiBone in addition to our new behaviours specifically built for the game. For this game we developed five new expressive behaviours: digging, point left, point right, point down and point up. The digging behaviour is being triggered directly from the robot's chin sensor and at the same time informs the interface through the Linker for this action. The pointing behaviours inform the user for the relative hidden bone location and are triggered from the interface through the Linker. Additionally we developed a complementary behaviour to support the ball tracking routine and offer a better human-robot experience to the user. This behaviour adjusts the AIBO's body position according to the relative ball location in order to prevent awkward neck angles in case the ball goes out of AIBO's visible field. This behaviour also keeps the AIBO on a fixed distance from the tracking ball by moving backwards or forwards depending on the distance of the moving ball. These calculations are made based on the size of the ball on AIBO's camera and it is based on the natural phenomenon where the object's size is proportionally related to the distance of the viewing position.

3.4.3 AIBOStory platform

Both AIBOcom and AiBone allowed two users to connect with each other and at the same time play a collaborative game with each other. For our third study we decided to use a different communication platform which allowed two or more users to interactively exchange stories through a computer interface linked with two AIBO robots. Our newly developed platform AIBOStory (Figure 20), introduced a multiple user handling through a dedicated server application that allowed many users to contribute to the task simultaneously.

Figure 20: AIBOStory platform

AIBOStory’s interface introduced the user identification function that allowed users to login into the system with a unique userID and password in order for the system to allocate them with different settings and log files. AIBOStory's server application supports multiple connections from users as long as the userID exists in the server's access list. By dividing the system into the interface and the server, we managed to run the interface application on low hardware specification computers such as tablets, as the server application is located on a desktop computer. Additionally, the interface contains significantly less code than our previous platforms as the robot managing and synchronisation routines are located on the server application. Furthermore, the interface application is used only for graphical representation on the screen therefore, no special routine calls or interconnections with DLL files are necessary. The interface application could be programmed in various high-level languages and it can run on low hardware specification devices such as mobile phones, tablets and as flash content on internet browsers.

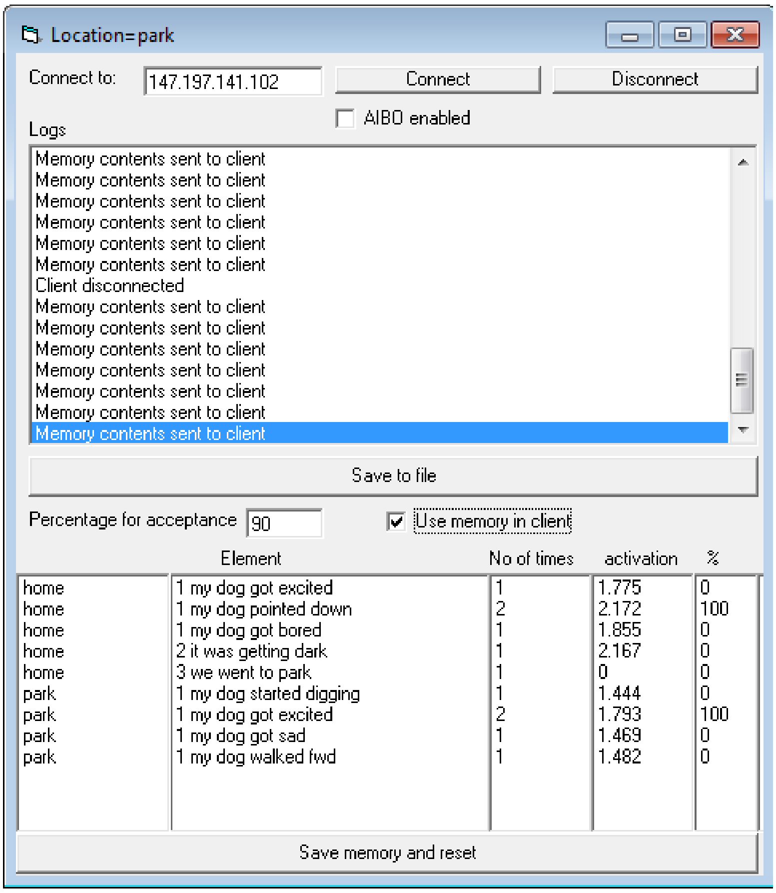
3.4.3.1 Interface

AIBOStory's interface (the client) is responsible for displaying the story elements and various other important information to the user while the low level AIBO communication is handled from the server application. The client application connects to the server by utilising the TCP/IP protocol and a simple user authentication routine. The server loads an authentication list on start-up and stores the accepted usernames and password into a list. Upon a client-server connection request, the client sends the user data to the server and the server compares the data with the user list. If the data matches then the server accepts the connection and starts the data synchronisation with the client otherwise it drops and closes the connection. The client consists of two main parts, the story and the story elements (Figure 21).

Figure 21: AIBOStory interface

The story area is a drag and drop control box which allows users to drop story elements sequentially. The story elements area is categorised into three different groups, AIBO related, Scene related and Location related where each category is selectable from the user and corresponds to different story settings. Additionally, the elements area includes two progression bars used for representing the current internal states of the AIBO. The client's options are hidden when the connection with the server has been established but they are accessible through a mouse right click menu option. In this option dialog box the user can define his own personal and unique nickname for his AIBO robot and the story elements will be adjusted accordingly.

Currently, the client supports ordinary computer screen resolutions and tablet screens. The user can select the option to change the layout of the client when it is running on a tablet computer and the client software will adjust the layout and the resolution automatically. A complete description regarding the client's functionalities can be found on Chapter 6.



Connect to: 147.197.141.102

☐ AIBO enabled

```
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Client disconnected
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
Memory contents sent to client
```

Percentage for acceptance 90

☑ Use memory in client

	Element	No of times	activation	%
home	1 my dog got excited	1	1.775	0
home	1 my dog pointed down	2	2.172	100
home	1 my dog got bored	1	1.855	0
home	2 it was getting dark	1	2.167	0
home	3 we went to park	1	0	0
park	1 my dog started digging	1	1.444	0
park	1 my dog got excited	2	1.793	100
park	1 my dog got sad	1	1.469	0
park	1 my dog walked fwd	1	1.482	0

Figure 22: Server application

The server application (Figure 22) handles all the communication between the client and the AIBO robot through the dedicated Linker library and the interface is mainly used for debugging purposes. It is equipped with a multiple TCP/IP connection handler control to allow one or more active connections from the clients at the same time. The server utilises the Linker library to connect to the AIBO robot and execute various behaviours derived as tasks from the story application. It also stores personalised information for each user independently in a simple database and keeps a memory record for each session. The memory algorithm is based on the repetition and recency of the incoming events from the users and the memory map is displayed through a list box window in the server (Nuxoll, Laird, & James, 2004; Nuxoll, Tecuci, Ho, & Wang, 2010). The algorithm is based on the activation history of the previous sessions and the activation value is calculated based on a variant of the base-level activation model proposed by (Anderson et al., 2004):

$$A = \ln \left(\sum_{j=1}^{n} t_j^{-d} \right)$$

Figure 23: Memory activation value formula

In this formula (Figure 23), the letter n defines the number of memory activations, t_j is the time since the j_{th} activation and finally, d is used to define a custom decay parameter for the formula. For our experiment we used a d value of 80 as it produced the most usable memory results on our pilot trials. The memory section of the server interface (bottom part of Figure 22) is divided into five sub windows in order to deliver the memory information categorised. The first window displays the location of the occurred event while the second shows the actual event. The third window informs us about the frequency of the selected event while the next window shows the calculated activation value based on the activation-based selection algorithm. Lastly, the fifth window displays the relevance of the incoming data to the already stored data based on a comparing algorithm and by using a predefined percentage value in the server. This value will be used against the comparison and will accept any result with a greater percentage value into the same memory record; otherwise a new record will be created as the incoming data will be considered as new to what is already stored for comparison. This comparison algorithm is used to avoid unnecessary additional memory records which will reduce the effectiveness of the memory algorithm. A default value of 70% have been chosen after the pilot study but this value can be changed anytime through the interface of the server application. The memory feature is available when the AIBO robot is enabled and active and this option can be activated or deactivated prior a session from the server window. Each user is assigned with a unique database file for the memory and the logs which are retrieved automatically on every successful request from a client for personalised memory utilisation.

3.4.3.2 Linker

In AIBOStory we used the previous Linker version with some minor changes for the additional AIBO expressive behaviours required for the story representation.

3.4.3.3 AIBO

Similarly, the AIBO software was based on our previous implementations with several additions mainly regarding the new expressive behaviours required for the story development. In this version, AIBO robots are capable of executing 16 different behaviours as shown in the table below:

Bored	Walking forward
Happy	Walking backwards
Excited	360 degree rotation
Tired	Sitting down
Digging	Standing Up
Point Down	Random barking
Sad	Ball tracking for 15 seconds (with proximity features)

Table 2: AIBOStory expressive behaviours

These 16 behaviours can be executed directly from the interface when a user selects an AIBO related story element. During a storytelling session, both AIBO robots run in autonomous mode and can execute the first four behaviours from Table 2. The autonomous execution freezes the storytelling session thus preventing the users to select new elements until both AIBOs finish their active behaviour. The ball tracking behaviour is the game controlling routine that has been used on both AIBOcom and AiBone versions. In this version we converted the ball tracking behaviour as a 15 second behaviour to allow the user to play with the AIBO by using the provided pink ball when this behaviour is called within the interface.

3.5 Evaluation in HRI studies

Besides the design and implementation of a remote communication platform, this research requires multiple Human-Robot Interaction studies with multiple participants in order to evaluate our systems. In this section we will list and briefly describe the three research studies that we performed in order to highlight the design of evaluation studies of robots as social mediators in remote communication scenarios. Details of the studies will be presented in the following chapters.

During this three-year PhD research, we performed various experiments where each one was designed differently in order to answer each one of our research questions and furthermore, to explore any human-robot and human-human effects derived from the interactions from our communication platforms.

For the first study, we utilised an AIBO robot as social mediator and a computer interface to socially connect the participants by playing a collaborative game. In Chapter 4 we describe the implementation, testing and evaluation of the first prototype of the “AIBOcom” system, which allows remote users to play an interactive game cooperatively each using a pet-like robot as a social mediator. An exploratory pilot study tested this remote communication system with 20 users (10 pairs) who were exposed to two experimental conditions characterised by two different modes of synchronisation between the two robots that each interacts locally with its user. In one mode the robots incrementally affected each other's behaviour, while in the other, the robots mirrored each other's behaviour. This chapter focuses on the analysis of questionnaire data and behavioural data, which was divided into two groups in order to investigate human-human and human-robot engagement level and synchronisation. We used various techniques to measure engagement and synchronisation such as quantitative (rate of occurrence, average values) as well as qualitative measurements.

In Chapter 5 we present the effects of an autonomous robot on human-human remote communication in comparison with a Conventional mode using keyboard and mouse. We developed a platform called AiBone that supports communication either through a robot or by using conventional devices. AiBone is a remote communication system that aims to enable two participants to play individually with their robot while they simultaneously cooperate with each other in an interactive collaborative task through existing video communication software by utilising two AIBO robots. An exploratory study involved twenty pairs of participants who used both types of input modes (robots and no robots) while communicating using video conference software. Each pair of participants utilised both the robotic and the conventional devices to play an interactive game while they communicated using video conference software. Instruments used in this study include questionnaires, video observations and log files for the game and the robots' states.

Lastly, our third study (Chapter 6) focused on long-term interactions and on non-competitive tasks that allowed the distant users to interactively share stories through a computer interface named AIBOStory along with robotic companions which operated as social mediators. AIBOStory has been designed to work with online chat software and aims to enrich remote communication experiences over the Internet. A pilot study was conducted prior to the long-term experiment in order to evaluate the proposed system's use and acceptance by the users. Five pairs were exposed to the system, with the robot acting as a social mediator, and the results suggested an overall positive acceptance response. The system was later evaluated through a long-term study which involved 20 participants in order to compare their preferences between a robot that utilises a computational memory model and a non-robot mode. Instruments used in this study include multiple questionnaires from different communication sessions, demographic forms and logged data from the robots and the system. We used various techniques such as quantitative (e.g. rate of occurrence and median values) and qualitative measurements (e.g. story continuity/sense) to measure user preference and human-robot Interaction.

Chapter 4: AIBOcom – initial exploratory experiment

4.1 Introduction

Chapter 1 described the remote communication limitations due to the lack of physical interactions and generally the lack of alternative interactive and engaging social activities between the distant users. In order to investigate the impacts of an intelligent robot on remote communication, we developed a novel computer application named 'AIBOcom' (Papadopoulos, Dautenhahn, & Ho, 2010), which socially connects users with the help of interactive robots.

Communication between the users is established and maintained through ordinary video conference software, while physical interaction is established through the AIBOcom platform. For physical interaction we decided to use robots in conjunction with computers, in order to allow the users to play a cooperative and interactive game together due to the irrefutable exposure to and familiarisation of the public with computer and console games nowadays, a goal-oriented game was developed (maze game). AIBOcom (Figure 24) is a remote communication system that allows two users to play with their robot individually and to cooperate with each other in an interactive game through existing video communication software by utilising two AIBO robots, therefore maintaining and enriching the distant relationship (Bos, Olson, Gergle, Olson, & Wright, 2002). AIBOcom controls two AIBOs, each interacting with a remote user and providing the ability to engage in a two-player game. Human-Robot Interaction was designed and developed bearing in mind both the robot and human perspectives for robot "sociability" (cf.(Breazeal, 2003;Dautenhahn, 2007a)). In this game, users were required to guide their virtual characters out of a maze (Figure 25 – right-hand side) using their AIBOs as an interaction tool, while at the same time interacting with the robot. Importantly, each robot is an *autonomous system* with its own set of behaviours, sensing abilities and internal variables ("needs", cf. (Avila-García & Cañamero, 2002; Meyer & Guillot, 1991)), and the user is expected to interact with the AIBO like a real pet in order to manage these dynamic changes.

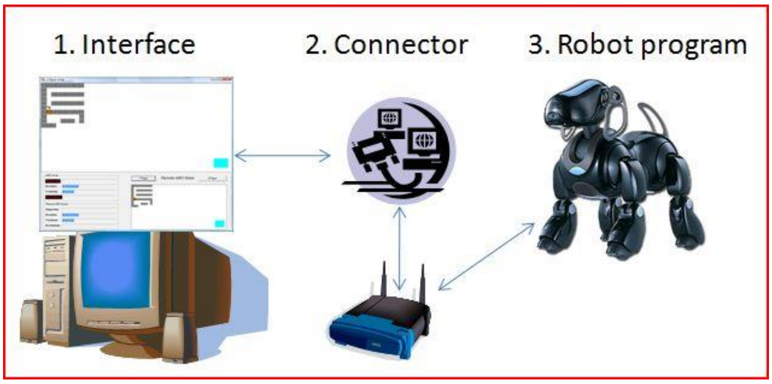


Figure 24: AIBOcom system components for each user. The interface and connector are located on the computer side, while the robot program runs on the robot's hardware.

During the game, the AIBOs autonomously execute dog-like behaviours (cf. (Kahn et al., 2004; Kerepesi, Kubinyi, Jonsson, Magnusson, & Miklósi, 2006)) triggered by changes in the robot's internal variables. In order to complete the game, both users have to cooperate and negotiate using voice and body gestures to converse using the online video conference program and by interacting with their robots. This cooperation is essential, since each AIBO continuously influences the other AIBO's internal states.

The purpose of the first experiment was to identify users' preferences for robot-mediated human-human interaction, as well to investigate their overall acceptance of the system. Initial findings, considering only questionnaire data, indicated that users showed a greater preference for one particular playing mode (mirroring) and that they generally enjoyed and embraced the proposed robot-assisted remote communication function (Papadopoulos et al., 2010).

In order to identify and extract useful Human-Robot Interaction data from the AIBOcom's social mediator game, we used additional data collected during the trials. Our main research goal was to identify meaningful links among experiment results, observable data and game states, thus helping us to understand various interaction aspects of the proposed social mediator scenario and to allow us to design and improve future architectures for robot-mediated, remote social interaction and communication. During our experiment we collected data including video, questionnaires and game logs, which were later extracted and analysed. The video data included time and event information such as user's gazing, petting rate and speech events. Since the study involved two users interacting with each other at a given time, the AIBOcom system aimed to enhance the engagement process that users need in order to establish, maintain and then terminate their interaction (Sidner et al., 2005).

This chapter is organised as follows. Section 4.2 presents the key research questions and expectations. Section 4.3 and 4.4 describes the AIBOcom system and the experimental setup. Section 4.5 presents experimental and statistical results, section 4.6 discusses and analyses the results and lastly this chapter ends with the Conclusions section.

4.2 Research Questions

The main research question of our study was:

R1M: How should two interactive robots remotely influence each other's behaviour in order to enhance audio and video (AV) communications between two remote humans? Specifically, which of the two modes of robot-robot communication implemented ('mirroring' and 'affecting') are preferred by the participants?

The system was designed to be extendable and to demonstrate different game modes. We included two game modes initially in order to test whether participants perceived and reacted differently to remote interaction via the robots. Our hypothesis was:

H1: **Most participants would enjoy and prefer the mirroring mode over the affecting mode.**

We expected that the mirroring game mode, (as explained below in detail), might be more preferred by participants because it is a mode where both robots behave more similar to each other which is likely to support a closer collaboration and thus better game performance of the participants. First results from questionnaire data supporting this hypothesis were presented in Papadopoulos et al., 2010. This chapter analyses a large amount of behavioural data that was collected during the experiments in the light of the further deepening of these results.

Further research questions are:

R1Q1: *Are there any general meaningful links among the experiment results?*

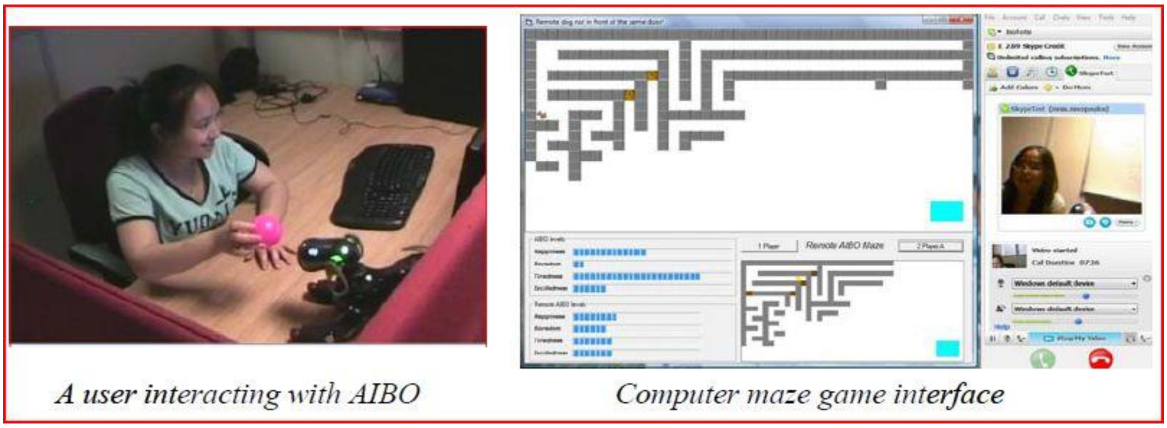
R1Q2: *Are participants influenced by remote users' behaviours and postures?*

R1Q3: *Does the human-human and human-robot synchronisation have an effect on cooperative performance?*

Generally, we anticipated that participants' behaviour and interaction will be affected by the remote participant because of the fact that they can see and hear each other through the existing video communication during the game. Direct gaze on the participant's interaction with the robot could influence the observer (other participant), especially when both participants are playing with the same game and robot cooperatively. Furthermore, we believe that the pairs of participants who managed to synchronise their robot behaviours and interaction, would achieve better game performance scores because cooperation-based games require a good level of synchronisation. Lastly, we expected that participants would interact with their robot and the other participant differently depending on individual differences, e.g. their age, because novel technology is usually better accepted by younger persons although the sample size of this study was insufficient for identifying statistically significant correlations for data relating to demographical profiles.

4.3 System overview: AIBOcom

The AIBOcom software allows two robots to be connected to a computer and handles the synchronisation between robots and participants. The main goal of the maze game is to guide a virtual character to the exit of the maze with the help and cooperation of the remote participant. Participants utilise the AIBO robots in order to navigate in the virtual world and express their intentions by interacting with them. The robots can interpret the type of interaction and influence the various embedded internal states accordingly. Note, different from haptic devices such as joysticks, the robots used in our system are not pure input/output devices but are autonomous robots which possess goals, internal states and are able to initiate interaction. The main control of the computer screen character is a pink ball moved in front of the AIBO's visual field. The AIBO robot moves its head to follow the ball, and the virtual character on screen moves horizontally or vertically inside the maze accordingly (Figure 25). The participant on the remote side also controls such a virtual character and the maze includes locked doors which require the participants to co-operate to open them.



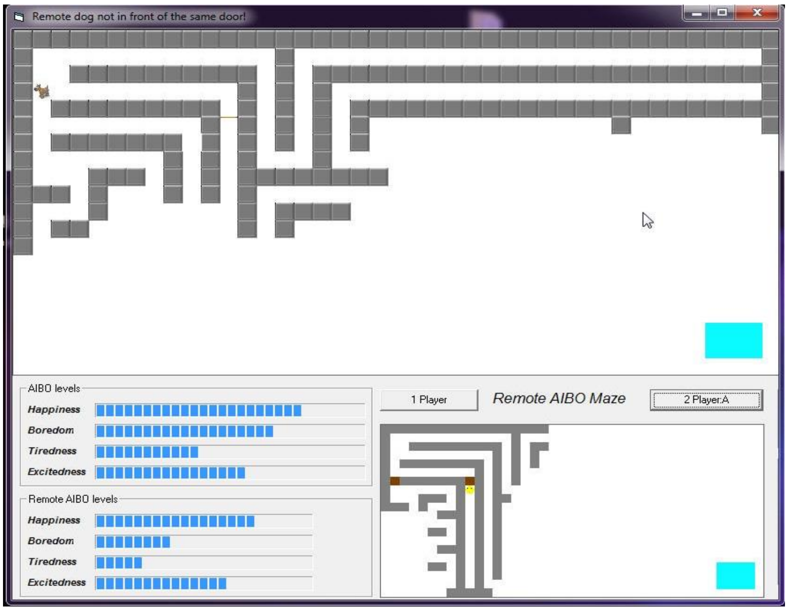
A user interacting with AIBO *Computer maze game interface*

Figure 25: Two participants playing the AIBOcom game in affecting mode. Player 1 can been seen on the left interacting with the AIBO, along with the game interface (middle) and the Skype window with the active video communication on the right.

<u>The game has two modes</u>:

Mode 1 is a mirroring mode. Both participants control the same virtual character and both only see one character on the screen. In this mode, the mini maze representation on the bottom of the interface mirrors the actual common maze that both participants see and share (Figure 25 – Right). Every movement they carry out via their AIBO and the pink ball is averaged, and combined with the movements suggested by the other participant. Thus, goal-directed movements in the virtual maze only succeed if both participants cooperate and synchronise their own movements through Skype using voice and video gestures. Furthermore, graphical representations (directional arrows) of the remote participant’s desirable direction displayed on the local interface in order to inform the participant and allow him to synchronise. During the game, every interaction with the local robots (i.e. petting) affects each robot’s internal states (Happiness, Excited, Boredom and Tiredness). These are then synchronised with those of the other robot, thus influencing the remote robot’s behaviour and vice-versa. As a result, the robots mirror each other’s behaviours and internal states. From an external observer's point of view both robots may appear to be controlled by the same program, but they are in fact operating autonomously with sensory input augmented from the remotely located robot.

Mode 2 is an affecting mode. Each participant controls their own virtual character, but can see the other participant's virtual character on a separate mini-screen in order to synchronise their movements instead of the directional arrows in mirroring mode. Both participants have to guide their virtual characters in front of the same locked door and pet their AIBOs in order to unlock it. Furthermore, since each robot is independent from the other, in terms of their respective internal states, both participants also have to satisfy (with petting) their local robot's individual needs. Otherwise doors will remain locked, or the virtual character will not move if the real robot feels "tiredness or boredom". Also, whenever a robot's internal state reaches a certain threshold, it will execute a predefined expressive behaviour (e.g. "tiredness", "happiness" etc.) and at the same time it will send these values to the other remotely based robot, thus affecting the remote robot's internal state variables. The game interface also includes four bars which reflect the current (internal) states of the local AIBO, which currently includes "boredom", "happiness", "friendliness" and "excitement".



Remote dog not in front of the same door!

Figure 26: Game interface. The maze at the top displays the current game session with the virtual character along with visualisation of the robot's internal states shown in n the bottom left corner. The bottom right picture displays the remote participant's game state

These bar values (Figure 27) apart from being affected directly from each participant's petting, they also change over time to simulate (in a simplified manner) dynamically changing aspects of real dog behaviour and needs. Each participant can also see the remote participant's robot's internal states in the same screen in order to coordinate their movements and achieve their common goal apart from the mirroring mode where the remote bars are linked with the local bars as they share the same values.

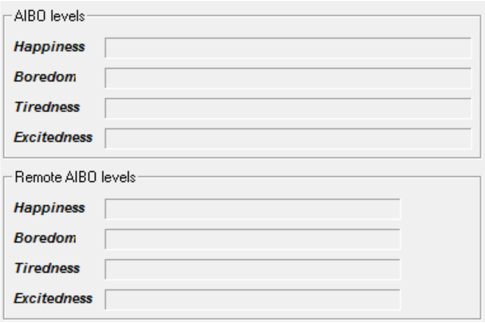


Figure 27: Game interface internal state bars (local & remote)

4.4 Experiment

In this section we describe the experiment setup along with the methods used to record and investigate participants' performance along with their interaction with the robot.

4.4.1 Participants

For the first experiment we used 10 pairs of participants (20 in total) aged from 15 to 50 (table 3) (mean 27.8 years). Since the study involved two users each time, we grouped the users in different combinations such as male to male, female to male, strangers, friends, family etc. in order to minimize, if not exclude the familiarisation factor.

	Pair 1	Pair 2	Pair 3	Pair 4	Pair 5	Pair 6	Pair 7	Pair 8	Pair 9	Pair 10
Relationship	Unknown	Friends	Unknown	Friends	Friends	Friends	Family	Family	Unknown	Unknown
Robot familiarisation (1-5)	2	3	4.25	4	3.5	2	1	1	2.25	2
Skype (hours/week)	7.5	23.7	13.7	3.7	18.7	56	62	2.5	58.7	81
Gender	Mixed	Female	Mixed	Male	Mixed	Female	Female	Mixed	Mixed	Male
Age	25.5	24.5	25	29.5	28.5	25.5	19	48	24	28.5
Age diff	5	3	4	5	13	1	8	4	2	7

Table 3: Demographic data

4.4.2 Procedure and Experimental Setup

Each participant was seated in front of a computer (Figure 25-left side) with an AIBO robot, and then started communicating with the other user located in a separate room using a combination of webcam and microphone through an Internet conference software, Skype[9]. Participants were given 5 minutes in order to familiarise themselves with the AIBOcom, and continued with the experiment as soon as they were ready. Five pairs of participants played the mirroring mode first and then progressed to affecting mode while the rest of the participants started with the affecting mode and progressed to mirroring mode in order to counterbalance the difficulty of each mode. Each room was equipped with a secondary video camera for capturing the behaviour of the participant, the robot and their interaction. In addition, AIBOcom recorded a series of log files which contained all user input and game states such as the virtual character position, local and remote

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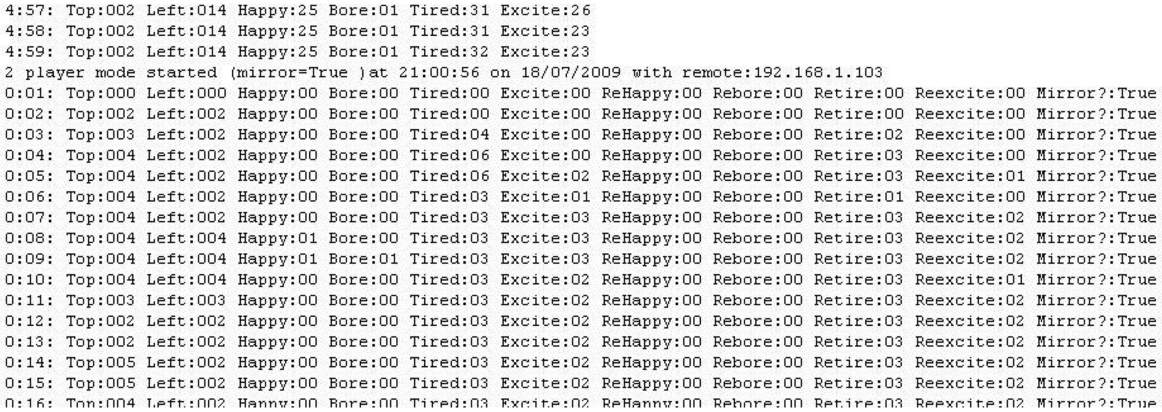
[9] www.skype.com, Video conferencing software, Last accessed May, 2012

AIBO internal states, game mode, date and time. An example of such file can be seen in Figure 28. The log files have been used in our statistical analysis after they have been extracted and inserted into Microsoft Excel. At the end of each run, participants were given a questionnaire in order to assess and comment on their game experience.



```
4:57: Top:002 Left:014 Happy:25 Bore:01 Tired:31 Excite:26
4:58: Top:002 Left:014 Happy:25 Bore:01 Tired:31 Excite:23
4:59: Top:002 Left:014 Happy:25 Bore:01 Tired:32 Excite:23
2 player mode started (mirror=True )at 21:00:56 on 18/07/2009 with remote:192.168.1.103
0:01: Top:000 Left:000 Happy:00 Bore:00 Tired:00 Excite:00 ReHappy:00 Rebore:00 Retire:00 Reexcite:00 Mirror?:True
0:02: Top:002 Left:002 Happy:00 Bore:00 Tired:00 Excite:00 ReHappy:00 Rebore:00 Retire:00 Reexcite:00 Mirror?:True
0:03: Top:003 Left:002 Happy:00 Bore:00 Tired:04 Excite:00 ReHappy:00 Rebore:00 Retire:02 Reexcite:00 Mirror?:True
0:04: Top:004 Left:002 Happy:00 Bore:00 Tired:06 Excite:00 ReHappy:00 Rebore:00 Retire:03 Reexcite:00 Mirror?:True
0:05: Top:004 Left:002 Happy:00 Bore:00 Tired:06 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:01 Mirror?:True
0:06: Top:004 Left:002 Happy:00 Bore:00 Tired:03 Excite:01 ReHappy:00 Rebore:00 Retire:01 Reexcite:00 Mirror?:True
0:07: Top:004 Left:002 Happy:00 Bore:00 Tired:03 Excite:03 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:08: Top:004 Left:004 Happy:01 Bore:00 Tired:03 Excite:03 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:09: Top:004 Left:004 Happy:01 Bore:01 Tired:03 Excite:03 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:10: Top:004 Left:004 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:01 Mirror?:True
0:11: Top:003 Left:003 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:12: Top:002 Left:002 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:13: Top:002 Left:002 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:14: Top:005 Left:002 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:15: Top:005 Left:002 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
0:16: Top:004 Left:002 Happy:00 Bore:00 Tired:03 Excite:02 ReHappy:00 Rebore:00 Retire:03 Reexcite:02 Mirror?:True
```

Figure 28: Example of log file contents generated from AIBOcom

4.4.3 Methods

For the video data analysis we used Noldus Observer XT[10] to analyse and code participants' behaviours. We used the following coding scheme for the videos:

i) Gaze

- Gaze at the screen
- Gaze at the robot
- Gaze at other

ii) Petting

- Pet on the robot's head
- Pet on the robot's back
- Pet on the rest of the robot's body

iii) Talk

<u>Socially Oriented</u>

- Talk to the robot
- Talk to the user
- Talk to other

<u>Task Oriented</u>

- Talk to the robot
- Talk to the user
- Talk to other

Using the following coding scheme we divided our study into two groups in order to investigate human- human and human -robot engagement level and synchronisation. We

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[10] Noldus Observer XT behavioural coding suite (2009) http://www.noldus.com/human-behavior-research/products/the-observer-xt, Accessed Aug 25, 2010

used various techniques to measure engagement and synchronisation such as quantitative (rate of occurrence, average values) as well as qualitative measurements. These techniques include analysis of Human-Robot Interaction, human-human synchronisation, robot-robot synchronisation and many more which are presented in the list below. Furthermore, in order to investigate the human-human synchronisation, we used kappa analysis (Landis & Koch, 1977) to compare the pair's proportion of agreements within a particular tolerance time window which was defined in the video analysis application.

The following analysis has been made in order to study any interrelationships between the subjects and any mutual events between them during the game:

Human-human engagement

- Speech to each other
- Users finished the game

Human-robot engagement

- Petting (rate of occurrence)
- Petting (which robot part)
- Gaze at the robot (rate of occurrence)
- Speak to the robot (rate of occurrence)
- Robot's internal states (average values)

Human-human synchronisation

- Talking to each other (proportion of agreements, 5 seconds time window)
- Mutual gaze at the screen (proportion of agreements, 2 seconds time window)
- Average distance between the virtual characters in the maze game

Human-robot synchronisation

- Internal states deviation
- Mutual robot petting (proportion of agreements, 2 seconds time window)
- Mutual gaze at the robot (proportion of agreements, 2 seconds time window)

4.4.4 Data Analysis

Human-human engagement includes data such as speech to each other and the number of participants who finished the game. Speech to each other was derived from the video analysis and shows the rate of occurrence that the participants talked to each other during the game. Large values indicate stronger human-human engagement since the game encourages them to communicate. We also recorded the number of successful game completions for each mode within the 5-minute time limit for each game mode. The number of completions shows how well the participants interacted with each other to finish the game. Human-robot engagement investigates the interaction between the participant and the robot. It includes the rate of petting which indicates the number of times a participant petted the robot either on its head or its back. Gazing and speaking to the robot shows the rate at which the participant interacted with the robot for each playing mode. The robot’s internal states include the average values of “happiness”, “excitement”, “boredom” and “tiredness”. These values are mainly influenced from the participant interaction therefore human-robot engagement can be measured for each participant in each playing mode. Human-human synchronisation on the other hand investigates the factors that possibly affected the game and interaction performance on each game mode. Talking to each other describes the proportion of agreements between the participants within a 5-second time window. These values show how quickly the participants responded to each other and whether the talking was just monologue or a conversation. Likewise, mutual gaze at the screen informs the proportion of agreements when both participants looked at the screen within a 2-second time window. Since the game requires cooperation, mutual gaze at the screen implies how well the participants synchronised with each other in order to achieve the same goal.

Lastly, the average distance between the virtual characters in the maze game calculates the number of blocks between the users’ characters. Large block numbers mean that the participants failed to coordinate and cooperate with each other having as a result characters in different locations therefore unable to open the locked doors in the maze game (see game description for more information). Human-robot synchronisation analyses the factors that influenced the performance of human-robot to robot-human interaction and includes the internal states' deviation between the robots and mutual gaze and petting at the robot. Each robot has its own set of internal states that are being influenced mainly from participant interaction. The deviation of each internal state ("happiness", "excitement", "boredom" and "tiredness") between the two active robots shows how differently the participants interacted with their own robot. Since the game requires synchronisation in order to succeed, this measure is directly linked with the robots' internal states to allow the participants to move freely inside the virtual maze. Finally, the analysis includes mutual gaze and petting the robot as a proportion of agreement within a 2-second window. These values indicate the synchronisation between the two participants in regards to when they pet and look at the robot.

In addition to the above, we also investigated the factors that influence user-user experience by using the provided demographic data such as their experience with robots and video communication software, their gender, age and age difference in each pair. In order to locate and compare links between the events we used a Bivariate Correlation table to highlight and extract the significant correlations. For the data analysis we used Microsoft Excel 2007[11] and SPSS 17[12]. For the calculation of significance we used the Pearson's coefficient (Cohen, Cohen, West, & Aiken, 2002). The correlation table flagged multiple significant cells. However, in order to extract meaningful information from the table, each correlation had to be individually investigated and explained. In order to evaluate the video coding reliability, a trained secondary observer coded 20% of the videos (8 randomly selected videos out of 40 for both game modes) by using the same procedure as the original observer. The observations of the secondary observer were compared with the original observations using Cohen's Kappa statistics (Cohen, 1960) in

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[11] Microsoft Office Excel (1985-Present) http://office.microsoft.com/en-us/excel/ Accessed Aug 25, 2010

[12] SPSS 17.0 statistics, http://www.spss.com/software/statistics/, 1968-Present, Accessed Aug 25, 2010

order to measure the interrater agreement (Gwet, 2002; Gwet, 2008) and excluding all agreements which occurred by chance.

4.5 Results

First, we present our initial findings (Figure 29-31) that originated from the questionnaire analysis which was performed in order to support our hypothesis H1 (cf. Section 4.2). The results are presented reflecting the basic questions addressed in the questionnaire: the number of users who successfully finished both games (mode 1 and mode 2) within the 5-minute time limit; how users enjoyed playing the game using 5-point Likert scale ratings for these two modes. Lastly, we asked which mode users preferred in the context of user-to-user cooperation preferences.

4.5.1 Interrater agreement

Table 4 shows the detailed inter-rater Kappa values for the 8 of the 40 videos that both primary and secondary rater analysed. The values of the table show the proportion of agreements between rater 1 and 2 along with the Cohen's kappa coefficient value in order to check the reliability of the scoring. At the bottom of the table average values are shown for each column. The Kappa values range between 0 and 1 and a value close to 1 indicates better reliability. Many researchers use the proposed Fleiss scale in order to interpret their reliability results where 0.40-0.60 values are characterised as fair agreement, 0.60-0.75 as good agreement and values greater than 0.75 as excellent (Fleiss et al., 2003). A Kappa value of greater than 0.60 is considered sufficient to ensure that chance by itself is not likely to have an effect on the agreement. The reliability analysis was performed with the use of a tolerance window of 1 second and aligned the observation times for accurate synchronisation. Results show that overall the interrater agreement is acceptable.

Participant - Mode	Proportion of agreements	Kappa value
11 – Affecting	0.72	0.65
11 – Mirroring	0.67	0.59
12 – Affecting	0.86	0.83
12 – Mirroring	0.71	0.63
14 – Affecting	0.80	0.73
14 – Mirroring	0.62	0.53
19 – Affecting	0.82	0.76
19 – Mirroring	0.89	0.85
Average	76.1%	0.696

Table 4: Interrater agreement

4.5.2 Users finished the game in mode 1 and mode 2

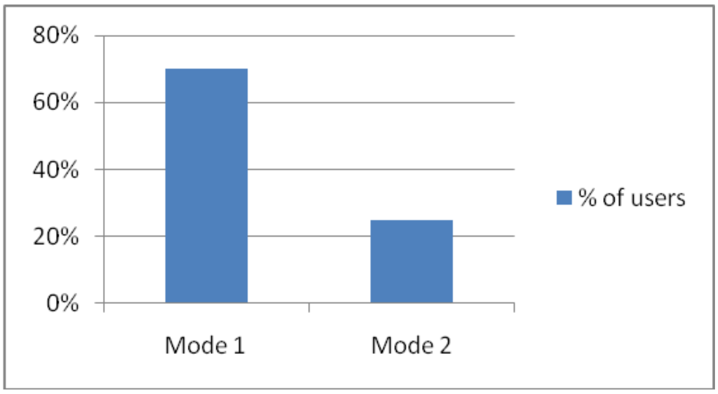


Figure 29: Game completions in mode 1

Figure 29 shows the overall completion scores of the users playing mode 1 and mode 2. More users finished the mode 1 game (mirroring), compared to the mode 2 game (affecting). A non-parametric Wilcoxon test was conducted to compare mode 1 and mode 2 for users who finished the game. A statistically significant difference between the completion rates of mode 1 and mode 2 was found (Z= -2.496, 2 tailed Sig. = 0.013). More users completed the mode 1 game compared to the mode 2 game.

4.5.3 Level of enjoyment

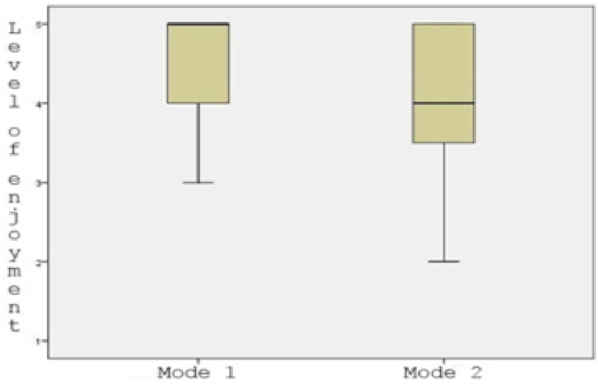


Figure 30: Level of user enjoyment playing the game in mode 1 and 2

Figure 30 shows the median values of the Likert (Likert, 1932) scale ratings from the questionnaire comparing users' enjoyment of mode 1 with mode 2. A non-parametric Wilcoxon test on users’ enjoyment ratings confirmed that a significant proportion of the sample stated that they enjoyed the mode 1 game more than the mode 2 game (Z= -2.179, 2 tailed Sig. = 0.029).

4.5.4 Cooperation preference between two modes

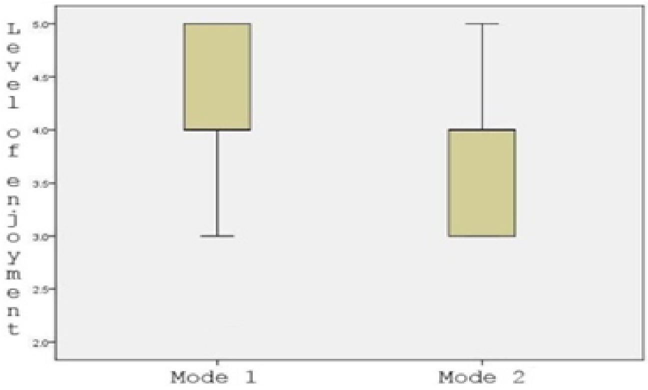


Figure 31: Level of user cooperation enjoyment playing the game in mode 1 and 2 grouped by relationship status

Figure 31 compares the median mode values gathered from the cooperation question for game mode 1 and mode 2 (1-5 Likert scale). A non-parametric Wilcoxon test found a significant difference in ratings (Z= -2.161, 2 tailed Sig. = 0.031) in favour of mode 1.

The graphs in the next sections (Figure 32-41) illustrate the data acquired from the video analysis, game logs and questionnaire forms after the statistical analyses were performed. The graphs contain values for both AIBOcom playing modes, which are then grouped into 10 pairs in order to compare the differences between them. Furthermore, since this chapter examines the correlations between events, each correlation is presented with two graphs along with its significant value.

4.5.5 Speech to each other – Distance between the virtual characters (affecting mode)

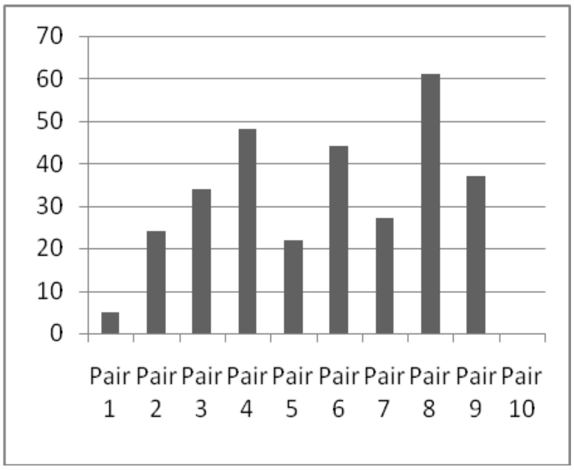


Figure 32: Speech to each other. The above graph displays the rate of communication between the users in each pair for the affecting mode

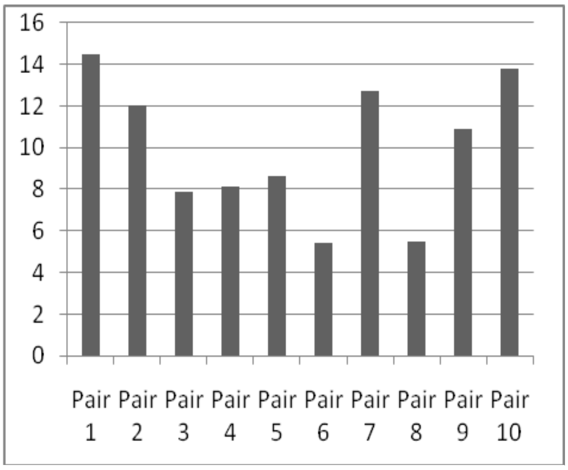
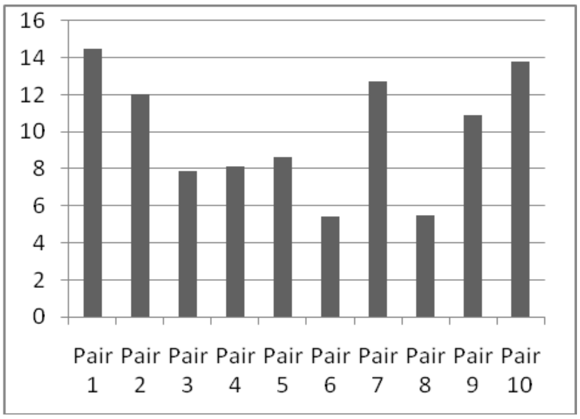


Figure 33: Distance between the virtual characters. This graph displays the average distance (in blocks) between the virtual characters in the maze of each user for the affecting mode

Figure 32 above, shows the number of times that users talked to each other in a completed game in affecting mode. Figure 33 displays the average distance between users' virtual characters during the game in affecting mode. Values in Figure 32 are inversely proportional to values in Figure 33. A Pearson correlation statistical test was performed against these values and showed a significant correlation (Pearson correlation= -0.851, Sig. (2-tailed) = 0.002, Sig. at level= 0.01).

4.5.6 Internal states difference (excitement) – Distance between the virtual characters (affecting mode)



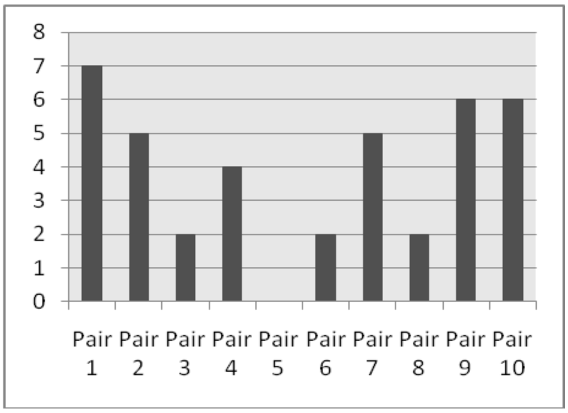
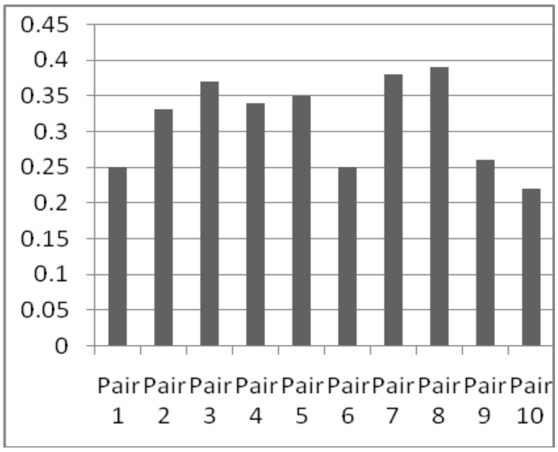


Figure 34: Distance between the virtual characters. This graph displays the average distance (in blocks) between the virtual characters in the maze of each user for the affecting mode

Figure 35: Internal state difference (excitement). This graph shows the variation between the two robots for the 'excitement' internal state values. Low values indicate small behavioural differences between the robots

Figure 34 represents the average "excitement" internal state variation of the robots for each pair playing the affecting mode. In Figure 35, values are significantly proportional with the values found in Figure 34 (Pearson correlation= 0.819, Sig. (2-tailed) = 0.004, Sig. at level= 0.01).

4.5.7 Mutual gaze at robots - Internal states variation (affecting mode)



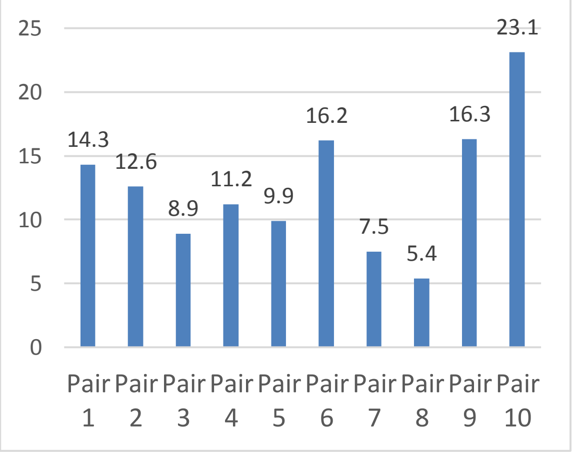


Figure 36: Mutual gaze at robots. This graph shows the average proportion of agreements between the users who simultaneously gazed at the robots within a 2 seconds time window (affecting mode). Higher values indicate better agreement

Figure 37: Internal states variation. This graph shows the variation of the internal states between the two active robots for every pair. The average difference value for each pair is displayed at the bottom of the figure. Low average values indicate small behavioural differences between the robots

Figure 36 pictures the average mutual gaze at robots from each pair of participants during mode 2 (affecting mode). Higher values indicate a better synchronisation (i.e. gazing at their individual robot at the same time) among the users. Figure 37 represents the average internal state variation values for every pair, categorised into “happiness”, “boredom”, “tiredness” and “excitement” levels. For every game, the robot’s internal state variation values of each pair have been calculated and the results have been used to evaluate the differences between participants’ robots. The resulted values derived from the summation of all comparisons between each internal state of each robot (e.g. Robot1.happiness-Robot2.hapiness+Robot1.tiredness-Robot2.tiredness etc.). A Pearson’s correlation test was conducted on the above graphs and revealed an inversely significant relation among them (Pearson correlation= -0.942, Sig. (2-tailed) = 0.0001, Sig. at level= 0.01).

4.5.8 Speech to robot – Video communication experience (affecting mode)

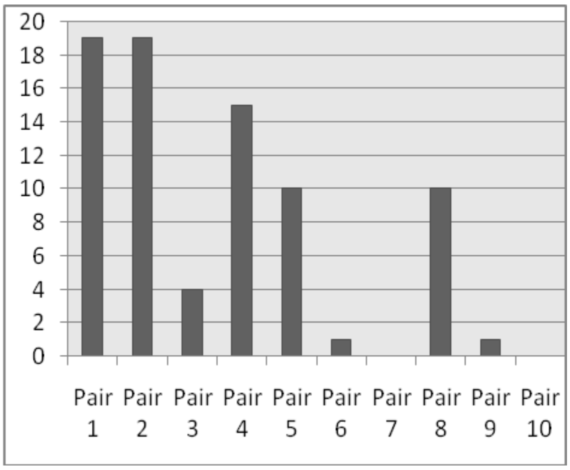


Figure 38: Speech to the robot. This graph displays for each pair, the number of times that both users spoke to their robots.

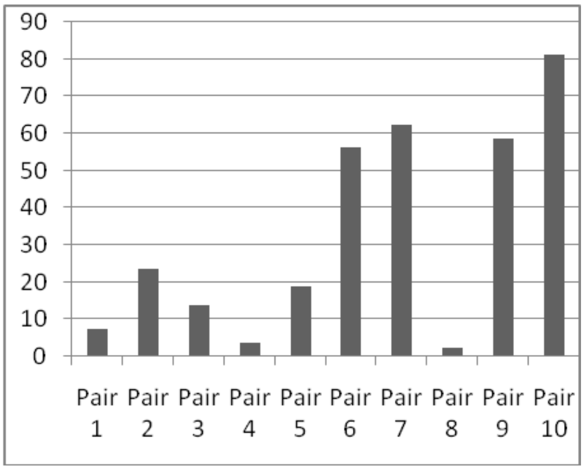
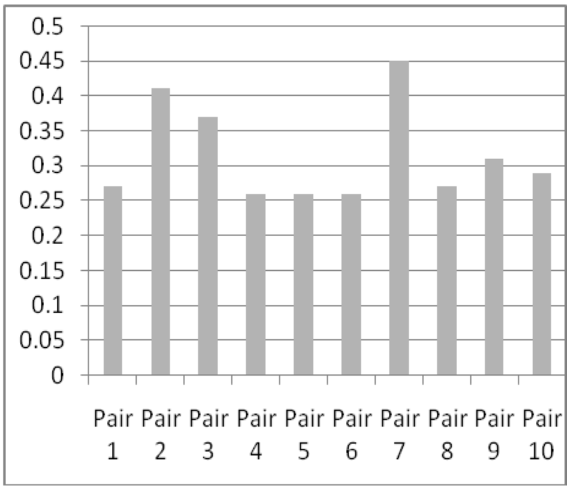


Figure 39: Video communication experience. The above graph shows the users’ computer-mediated communication experience (hours per week) prior to the study.

Figure 38 shows the number of times that each pair speaking to robot in the mode 2 (affecting mode) game. Figure 39, displays the video conferencing experience that users had before conducting the experiment. These values were taken from the demographics forms. A significant correlation which exists among these two sets of results has been confirmed by using the Pearson's test (Pearson correlation= -0.777, Sig. (2-tailed) = 0.008, Sig. at level= 0.01).

4.5.9 Mutual gaze at robots – Mutual gaze at screen (mirroring mode)



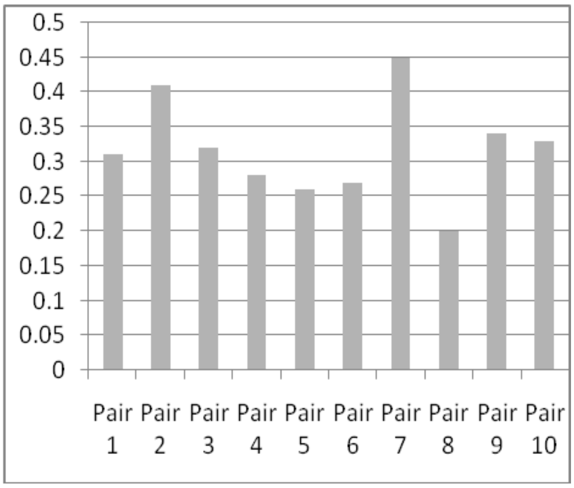


Figure 40: Mutual gaze at robots. This graph shows the average proportion of agreements between the users who simultaneously gazed at robots within a 2- seconds time window (mirroring mode). Higher values indicate better agreement

Figure 41: Mutual gaze at screen. This graph shows the average proportion of agreements between the users who simultaneously gazed at the screen within a 2- seconds time window (mirroring mode). Higher values indicate better agreement

Figure 40 depicts the mutual behaviour of gazing at robots for each pair. Similarly, Figure 41 displays the mutual behaviour of gazing at the computer screen during mode 1 (mirroring mode). A Pearson's correlation test performed on these results showed a highly significant correlation (Pearson correlation= 0.870, Sig. (2-tailed) = 0.001, Sig. at level= 0.01).

Table 5 below lists the significant correlations:

	Pearson Correlation	Significant value (2-tailed)
Speech to each other – Distance between the virtual characters (affecting mode)	-0.851	0.002*
Internal states difference (excitement) – Distance between the virtual characters (affecting mode)	0.819	0.004*
Mutual gaze at robots - Internal states difference (affecting mode)	-0.942	0.0001*
Talk to robot – Video communication experience (affecting mode)	-0.777	0.008*
Mutual gaze at robots – Mutual gaze at screen (mirroring mode)	0.870	0.001*

Table 5: Significant correlations summary table. (*=significant at 0.01)

4.6 Discussion

4.6.1 Questionnaire analysis

The questionnaire data (Figure 29-31) were analysed by performing the non-parametric Wilcoxon test. The results indicate significant differences for participant enjoyment, cooperation and game completion scores in favour of the mode 1 (mirroring) game. We suggest that participants find the mode 1 game cooperation more understandable and "direct" since they were interacting with each other during the game with no delays. Furthermore, mode 1 (mirroring) displays only one virtual character on the screen, which probably helped participants to realise the context and purpose of the game better than in mode 2 (affecting). The robots also behaved differently for the two game modes, and participants apparently rated the robot's behaviours better when the game was perceived as a "centralised system" (with the two robot's closely mirroring each other's behaviour) rather than as "individual displays" (with the two robots only influencing each other's behaviour but behaving differently from each other most of the time). These results indicate the effect of communication mode preference and set a clear direction for our future HRI studies that involve distant communication between humans. The "mirrored" communication that AIBOcom offers can provide the basis to form an enjoyable and suitable human-human communication environment integrated with multiple robots directly linked with each other. However, despite the fact that overall participants preferred the mirroring mode, they liked both modes and generally the game concept as they scored above the neutral point in the Likert scale on both enjoyment and cooperation preference questions. This suggests that researchers should consider the use of multiple communication modes between the distant participants, the game interface and the robots in order to evaluate each mode individually and utilise the most suitable and enjoyable one based on participants' preferences.

4.6.2 Video, Log files and demographic forms analysis

Our main research question has been answered using Pearson's correlation coefficient tests which pointed out multiple significant correlations between demographic data and recorded events identified in the behavioural data. As we carried out an exploratory but comprehensive statistical analysis in this very first study in this particular research direction, results presented here helped us formulate new research hypotheses in future studies, e.g. with other interaction scenarios and settings.

Below, we will discuss each one of the correlations that we presented in the Results section, and we will examine their importance to the experiment as well as any possible prospects for future experiments.

Both figures 32 and 33 show the correlation between the speech rate of occurrence of the participants in affecting mode and the average distance between the virtual characters in the game. The Pearson correlation analysis found a significant correlation among the recorded events. This correlation shows the importance of talking among the participants since it directly affects the AIBOcom game, as can be seen from the average distance the virtual characters had (Jensen, Farnham, Drucker, & Kollock, 2000). Higher values indicate longer distances among the characters which indicate a poor synchronisation between participants since cooperation is needed(both virtual characters behind the same door) in order to unlock the doors and move into the hidden parts of the maze. Summing up, results suggest that the higher the talking rate between the two participants, the better the synchronisation they managed to perform. Close observation of the video data clearly depicts an increase in communication between the users in an attempt to interact with a novel robotic social mediator due to basic humane curiosity. In particular, the AIBOcom game appeared to engage the participants to an increased verbal interconnection since the aim of the game was to achieve a common goal by synchronising their behaviours through AIBOs. This significant result indicates the importance of verbal communication on cooperative scenarios that involves humans and robots on both sides. Verbal communication helps humans to share their experiences with the robots and overcome any possible issues of interaction and cooperation with the robot.

Figure 34 and 35 represent the correlation between the robot's internal state variations and the distance of the virtual AIBOcom characters. The distance correlates significantly with the deviation of the "excitement" levels within a pair, which is supported by the Pearson's test. High deviation values indicate poor human-human synchronisation with regards to Human-Robot Interaction when trying to achieve "excitement" in the robot. On the contrary, low deviation values indicate that the participants within each pair managed to synchronise their robot's interaction. In practice, this caused the matching of both robots' internal "excitement" states simultaneously. This correlation indicates that low deviations of internal states and especially of the "excitement" levels, lead to better human-human synchronisation in regards to game play since their virtual character average distance was lower. Furthermore, the correlation highlights the importance of having two distant robots synchronised with regards to human to robot interaction since remote cooperation and task performance have been enhanced significantly. Therefore, the game encouraged the participants to get the AIBO robots into "excitement" states by petting them since then the virtual character could unlock the locked doors and move freely inside the maze.

Figures 36 and 37 demonstrate the relation among the mutual gazing at robot and robot's states for each pair. The term "mutual gaze" at robots describes the common period of time that both participants spent in each group looking at the robots. Higher values in Figure 36 indicate better human-robot to robot-human synchronization for the reason that participants looked and interacted with the robot at the same time. The results in Figure 37 represent the robot's average internal states values which are summarized at the bottom of the graph separately for each pair. "Mutual gaze" at robot values correlates significantly with the robot's internal state levels. The correlation can be explained from the fact that participants who synchronized their interaction and gaze with the robots (Cherubini, Nüssli, & Dillenbourg, 2008) managed to keep the robots more active. Therefore, synchronisation between the participants has positive effects on robots synchronisation, interaction and an overall proven exciting, game experience. Mutual gazing at robots is very important in remote cooperation tasks when robots are utilised as interactive devices and intelligent robot companions. Human-Robot Interaction frequency is closely related with the given task and correlates significantly with peoples' intentions.

Moreover, Figure 38 displays the speech rate levels for each pair in affecting mode which significantly and inversely correlates with the video conferencing experience levels as shown in Figure 39. The speech graph data results from the number of talking events to the robots within each pair. In order for a recorded speech to be considered valid and count as talking, it has to be more than 2 seconds long and must be focused directly on the robot. Similarly, video experience, as judged by the participants, has been considered only if it related to video communication tools using cameras such as Skype or MSN video. The graph shows the time (hours) that each pair approximately spends every week on video communication. The correlation exists because of the fact that participants with past experience of communication tools are familiar with communicating over the internet and therefore, are presumably less motivated in talking to the robots. Probably it is because they tend to focus more on either their conversation towards each other or other aspects of the game.

On the other hand, the mirroring mode produced less significant results compared to the affecting mode. Figures 40 and 41 compare the “mutual gaze” at the robot and the screen of each pair where the values of the graphs are highly correlated. The gaze correlation could only be found in the mirroring mode where participants are required to synchronise their behaviours in real time in order to achieve the goal of the game. Furthermore, AIBOs were synchronised with each other and shared the same internal states and behaviours. This correlation indicates the importance of synchronisation between the participants when performing a common task over distance by utilising robots as controllers and feedback devices. The haptic feedback that is being retrieved simultaneously from both participants, as the robots behaviours and internal states are directly linked, affects the participants’ robot control and manipulation. Lastly, since participants shared the same virtual maze and the same game state, they were eventually required to cooperate and synchronise their behaviours in order to succeed (i.e. finish the maze).

Generally, based on the significant correlations shown above and along with the participants' questionnaire data regarding game mode preference, it is shown that participants preferred the mirroring over the affecting mode. The mirroring mode preference confirms and supports our previous findings which were based on the questionnaire data that participants supplied after they played with both game modes. Participants who played with the affecting mode required more effort to finish the game compared to the mirroring mode. In particular, the affecting mode required the participants to work harder in order to control their screen characters due to the fact that two virtual characters can follow different routes in the maze and therefore, demand more time and effort from the participants to finish the game. Less significant correlations indicate that participants were more relaxed about human-human synchronisation and therefore produced randomised events and data, although technically the mirroring mode is more synchrony oriented.

4.7 Conclusions

Most of the related HRI studies focus on one robot and one participant and sometimes on two participants interacting with one robot. Thus, the results from this study contribute to distant HRI where two robots are utilised by two distant participants to deliver an enhanced remote experience. This study focused on systems like AIBOcom where two participants interact with each other remotely by using the robots as social mediators. The statistical results, data analysis and observational data provide interesting and useful information that could be used as guidelines for similar future studies and provide multiple significant results which address our first research question (R1Q1).

Although our exploratory results indicate that participants preferred the mirroring mode over the affecting mode, it should be noted that the interaction mode is highly dependent on the task of the interaction and communication between the participants. In our study participants preferred the mirroring mode since they found it more enjoyable for the task-oriented game. Furthermore, the study revealed the importance of verbal communication between the participants as it allowed them to discuss and share various aspects of the game and their interaction with the robots. Using intelligent devices for controlling the interface such as AIBO robots revealed the necessity of continuous communication among the distant participants. Human-Robot Interaction often requires guidance, especially when robots are utilised similarly to complex interactive haptic devices as in our system. However, thanks to video communication, the participants were able to exchange useful and constructive information that helped them to overcome difficulties with robot interaction and interface control. These findings highlight the significance of human-human cooperation and positive influence on their behaviours and partially address our second research question (R1Q2). Participants benefitted from the simultaneous haptic feedback from the robots in the mirroring mode as it guided them to perform the common game task more efficiently. The mirrored robot behaviours and linked internal states enhanced participants' awareness of presence, as the controlling and manipulation of the robots was done in a more enjoyable and interactive way which simulated the sensation to the participants of operating one robot instead of two distant ones. Participants performed more efficiently when using the mirroring mode and the results above have shown the importance of human-human and human-robot synchronisation and the significant positive effect on overall experience in our system. The above significant correlations answer our third research question (R1Q3).

A majority of participants enjoyed both game modes (mirroring and affecting) and most managed to finish the games within the 5-minute period allocated. Our findings support the initial hypothesis (H1) that participants prefer playing the game in the mirroring mode (R1M). The results of this study suggest that various demographic differences and significant correlations exist between the groups. Higher talking rates between the participants lead to better synchronisation which reveals the importance of verbal communication over the internet. Furthermore, the human-human synchronisation have positive effects on robots' synchronisation providing better interaction and game experience to the participants. Additionally, another correlation that strengthens human-human synchronisation is the ability of the participants to link their robot's internal states during the game.

Findings and conclusions derived from this study formed the basis of our next studies (Chapter 5, 6) on robot mediated software for enhancing distant human-human communication. The main significant result from this study was the communication mode preference and in our exploratory study participants have chosen the mirroring mode as the most enjoyable and preferred one. Our next study will exploit the mirroring features, adapted accordingly to a new interface and platform. Furthermore, the study also revealed multiple significant results on participants' interaction patterns with the robots and the remote participants. The extensive video analysis revealed various methods for measuring qualitative and quantitative information, which helped us to formulate the basis for a measurable human-robot and human-human interaction analysis. Measurement such as mutual gaze, synchronisation (robots and humans), number of smiles and speech during the communication can be used to evaluate the role of a robot as social mediator in remote human-human remote communication (RQ3). Based on the data as described above, we designed the new system accordingly and focused our investigation on specific issues and lessons learnt from the current study. Generally, the correlations and the differences found in this study reveal human and non-human factors that need to be carefully considered and addressed when designing a human-human communication tool with robots as social mediators.

4.8 Chapter summary

This chapter described the implementation, testing and evaluation of the first prototype of the "AIBOcom" system, which allows remote users to play an interactive game cooperatively each using a pet-like robot as a social mediator. An exploratory pilot study tested this remote communication system with 10 pairs of users who were exposed to two experimental conditions characterised by two different modes of synchronisation between the two robots that each interacts locally with its user. In one mode the robots incrementally affected each other's behaviour, while in the other, the robots mirrored each other's behaviour. Instruments used in this study include questionnaires, video observations and log files for the game state. We used various techniques to measure engagement and synchronisation such as quantitative (e.g. rate of occurrence and average values) as well as qualitative measurements. In an exploratory data analysis, these multiple sources of data reflecting user performance and characteristics were analysed. Significant correlations were found and presented between the users as well as users' preferences and overall acceptance of such communication media. Findings indicate that users preferred the mirroring mode and that in this pilot study robot assisted remote communication was considered desirable and acceptable to the users.

Chapter 5: AiBone – Comparison between conventional and robotic devices in a human-human collaborative communication

5.1 Introduction

Our previous study (see Chapter 4) showed positive results on various aspects of the system such as on Human-Robot Interaction, game preference and generally on the proposed communication system. Users enjoyed the communicative interactive game including the interface and the controlling of the virtual character via the AIBO robot. The game interface in the AIBOcom system had a lot of features that users found interesting and enjoyable such as the cooperation and linking behaviours between the robots. Moreover, they appreciated physical interactions with the robots, along with the autonomous behaviours that were triggered depending on the internal states influenced by the users. Overall, results from both questionnaires and video analysis revealed positive levels of enjoyment for robot-mediated communication and generally users' pleasure with the AIBOcom system. Finally, results from the AIBOcom study indicated a significant difference in enjoyment levels regarding the interaction modes, showing a preference towards the affecting mode compared to mirroring.

The result analysis of the AIBOcom platform led us in the direction of an interactive communication system, similar to AIBOcom and capable of offering enhanced features in communication through the support of games. For the new platform we used only one interaction mode (mirroring), along with similar game characteristics that users liked from the previous version such as the use of individual characters. The design and implementation of the new interaction system was based on useful and constructive comments taken from the questionnaire forms of the first study. Our previous study revealed positive enjoyment levels on robot-mediated communication therefore we assume that in the new communication platform, users would prefer and enjoy the robot mode over a conventional one without robots mediating the communication.

Lastly, questionnaire comments revealed that users found the AIBOcom system a little too short in duration, so we decided to increase the length of each experiment for richer human-robot and human-human interaction. Furthermore, a longer duration of human-robot interaction would reduce any possible technological novelty effects that robots might add to the system. Another weakness of the first study was the limited number of users who participated in our study therefore, for the new experiment we decided to recruit 40 participants.

AiBone is an enhanced version of our previous AIBOcom (Papadopoulos et al., 2010) platform and offers many new features, as explained in more detail in Section 5.3. AiBone is a remote communication system that allows two participants to play individually with their robot and to cooperate with each other in an interactive game through existing video communication software by utilising two AIBO robots. AiBone controls two AIBOs, each interacting with a remote participant and providing the ability to play a two-player game via the AIBOs. The advanced characteristics of this specific robot include multiple pressure sensors that can be utilised to identify the nature of the active petting, the high degree of freedom (DOF) of the legs and the head, thus allowing it to perform a large variety of movements, embedded wireless capabilities and a standalone processing unit capable of running complex programs. These specific characteristics meet our requirements for the robot’s role as a social mediator in this study. In this game, participants were required to guide their virtual characters through various game levels, in order to find randomly hidden rewards (“bones” in our dog-inspired scenario, Figure 42), by using their AIBO as an interaction tool. During the game, the design of which was inspired by the theme of dogs trying to find bones, the AIBOs autonomously execute dog-like behaviours controlled by the robot's internal variables. The game offers participants the option to co-operate and receive double points for each hidden bone they find, or they can search for them individually, either by negotiating to split the area between themselves or by searching randomly and individually. AiBone also offers the option to complete the game by using conventional input devices, which allows us to compare participants' experiences associated with the use of robots.

In this chapter we compare the two input modes by using our AiBone system with 20 pairs of participants (40 in total) and instructing each pair to play both modes. In the context of remote communication, and especially in our experiment, the enhancement of user experience is defined as an increase in social cues, tactile interactions and non-task-related speech expressed by the users. These measures are quantifiable and can highlight differences in comparative studies investigating tactile and non-tactile interfaces. Apart from studying the users' experience in these modes, we also analyse system limitations and any difficulties that the users experienced during the game in robot mode. Furthermore, we also analyse, present and compare the social cues noted between the users who played the game in both modes. Consequently, during our experiment we collected data including video, questionnaires, demographic forms, game log files and robot log files, which were later extracted and analysed.

The chapter is organised as follows. Section 5.2 presents the key research questions and expectations. Section 5.3 describes the AiBone system and section 5.4 the experimental setup. Section 5.5 presents experimental and statistical results, section 5.6 discusses and analyses the results and lastly this chapter ends with the conclusions section.

5.2 Research questions

The main research question of our study was:

R2Q: *Which of the two modes (Conventional and Robot mode) is preferred by the participants in the context of playing a two-player computer game, and which participant experience is associated with these two game modes?*

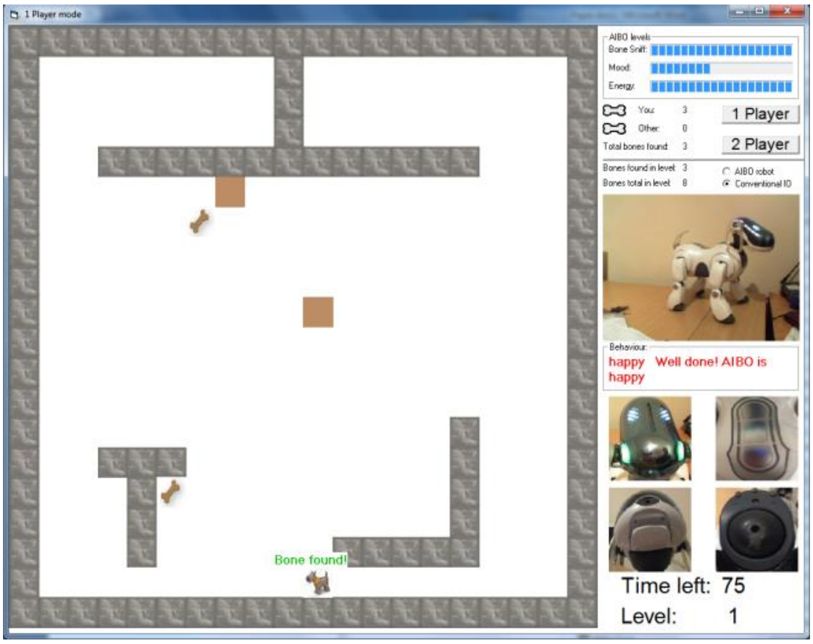
Our hypothesis was:

H1: **Most participants would prefer the Robot mode over the Conventional mode in their remote communication with each other.**

We expected that the Robot mode would be more preferable to participants. The first reason is that participants might find the Robot mode more enjoyable since the robot offers various expressive behaviours linked to specific game events and thus it is expected to make the game experience more interactive and engaging. Secondly, an increased level of engagement may lead to increased efficiency and thus an increased performance of participants in the Robot mode.

In addition to this research hypothesis we also studied any possible system limitations especially in the Robot mode. We were also interested to analyse social cues exhibited between the participants despite their mode preference. We anticipated that participants would express more social behaviours towards each other in the Robot mode compared to the Conventional mode.

5.3 System overview: AiBone



You: 3
Other: 0
Total bones found: 3
Bones found in level: 3
Bones total in level: 8
happy Well done! AIBO is happy
Time left: 75
Level: 1

Figure 42: AiBone game interface in Conventional mode

The AiBone software allows two robots to be connected to a computer and handles the synchronisation between robots and participants. The software consists of the interface which is a 2D maze game and the robot software that controls the robots. The robot control software is written in URBI (Baillie, 2004), a universal language that supports various robots, and that makes AIBOcom and AiBone a multi-robot platform. The main goal of the maze game is to guide a virtual dog-like character around various levels and find as many hidden bones as possible. The guidance of the virtual character can be done in two ways; either by using keyboard and mouse (Conventional mode) or by using the robot as an autonomous robotic helper (Robot mode).

In the Conventional mode the arrow keys control the character in the maze and the mouse helps the participant to cope with the deficit of various internal states (Mood and Energy) of the character by clicking on specific images (Figure 42 – bottom right). Each picture affects both “energy” and “mood” values of the robot depending on the area that the participant clicks with the mouse (Table 6) (e.g. the chin button increases the mood value significantly compared to a smaller increase after selecting the head or back buttons). These values reflect the same internal states changes that occur in the robot when a user interacts with it utilising the sensors accordingly.

	Head Button	Back Button	Chin Button
Mood value (Max 30)	+5	+2	+8

Table 6: Mood variable affect values from the game buttons

During the game, participants have to utilise the internal state values in order to efficiently guide their virtual characters. The energy value affects the speed of the character and when the value reaches a certain threshold, the character freezes until it regains its energy. The mood value freezes the character as well while the participants can cope with this by interacting with the provided buttons that affect the mood value. These buttons along with the associated animated AIBO picture, offer the participant a virtual representation of an AIBO robot allowing him to affect its virtual internal states similarly to those of the physical robot.

Frequency	Every 1.5 seconds				
Active Behaviour	Bored	Tired	Digging	Ball Visible	Ball Not Visible
Mood Value (max 30)	+1	0	0	0	-1
Energy Value	+1	+3	-3	0	0

(max 30)					

Table 7: AIBO internal states affect values from various behaviours

In the Robot mode, the control of the virtual character's movement is realised by real-time tracking of a pink ball moved by the participant in front of the AIBO's visual field. We preferred to use this method on interaction for the virtual character navigation in order to simulate a real dog ball game and to reduce the participant's cognitive load during the Human-Robot Interaction. As the AIBO robot moves its head to follow the ball, the character on the screen moves horizontally or vertically inside the maze accordingly. An example of a movement is when the participant wants to move his virtual character left therefore, he will need to drag the provided pink ball towards the left side of the AIBO in order to follow it. During the game, while the virtual character is wandering in the maze controlled by the participant, the robot performs various sniffing behaviours when it gets close to a hidden bone in order to help the participant identify the exact location. As the goal of this game is to find as many bones as possible, participants were motivated to search each maze level thoroughly. When the virtual character is in the radius of 2 game blocks from the hidden bone the robot automatically performs one of the 5 different behaviours depending on its relative position to the virtual bone on the game and while it is executing them, it provides physical feedback to the participant in order to help them locate the bones more efficiently. Therefore the behaviours physically direct the participant to guide the virtual character closer to the bone by pointing in the right direction. An example of such behaviour in a game arena with 20x20 game blocks (see Figure 42) is when a hidden bone is located 2 blocks away from the left side of the virtual character and AIBO physically points towards the left with its head while it is moving the left ear and playing back a sniffing sound.

Similarly to the conventional mode, participants have to keep the Energy and Mood values in sufficient levels in order to successfully wander in the game area and find the hidden bones in the given time. However, in the robot mode the various robotic images that allowed the participant to modify the internal states are not available any more. In this mode, AIBO robots are linked directly with the software and mirroring their internal states with the system. Consequently, every Human-Robot Interaction (e.g. petting) and the various AIBO behaviours affect the Energy and Mood level in accordance with the values of Table 7. The lower threshold for both Mood and Energy values have been set to 8 and the upper threshold to 27 for this study. Whenever the level of the Mood or the Energy reaches the lower value, AIBO executes the boredom or the tiredness behaviour consequently. The Mood and Energy levels are linked with factors such as Time, user interaction (e.g. petting or ball tracking) and active behaviour (Table 7).

Each level has a time limit of 75 seconds (selected in pre-trials as an appropriate time interval) and during this period the participants have to find the hidden bones that are randomly distributed in the maze. For every game level, a different bone distribution pattern was used (the same for all participants) in order to increase the difficulty level proportionally to the game level. The game interface also includes 3 horizontal graphic bars to display other useful information to the participant such as the virtual character’s energy and mood (internal states) and the sniffing value. The sniffing bar displays the virtual character’s relative distance from the bone and it reaches the maximum level when the virtual character stands directly on the bone location. The bar works similarly to the AIBO sniffing behaviour as mentioned above, however, it is limited only to visual information (i.e. sniffing bar value) to inform the participant about the proximity of the hidden bones. The sniffing bar is active and displays information about the hidden bones only in the Conventional mode. The main goal of the game is to find as many bones as possible within the time limit and through different levels. Importantly, the participant can earn two points when a bone is found as a result of cooperation with the peer. In order to collaborate, both virtual characters have to be close to each other whenever they dig for the bone. Both participants will receive two points only if their virtual characters stay close to each other until the bone is being excavated. Overall, if participants want to be efficient at each level, cooperation is highly encouraged to cover every spot of the maze and thus maximise the score in the limited time. Each participant can also see the remote participant's robot's internal states on top of their character like in an ordinary RPG[13] game in order to coordinate their movements and actions and achieve their goal of scoring high in each level more efficiently.

Generally, the Robot mode will allow the participants to share the robots' interactions and collaborate in order to achieve a common task. We designed the robot mode to mirror continuously the internal states therefore, the system can enhance users' perception of interacting together with a same robotic platform. Additionally, the presence of robots on both sides will allow the participants to exhibit more social cues with each other as the dog-like behaviours we designed offer an enjoyable Human-Robot Interaction (Pereira, Martinho, Leite, & Paiva, 2008).

5.4 Experiment

In this section we describe the experiment setup along with the methods used to record and investigate the users' performance along with their interactions with the robot.

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[13] RPG stands for Role Playing Game where users control small virtual characters on the screen and for every character a small bar is displayed on top of it showing information such as health, energy etc. By observing these bars, the user can coordinate and control its players (virtual characters) more efficiently.

5.4.1 Participants

For this study we recruited 20 pairs of male participants (40 in total) aged between 18 and 53 and paired randomly. We did not intend to investigate gender differences in this exploratory study, therefore, we used only male participants in our experiment. Most of the participants were University students while others were academic staff from various disciplines. Table 8 displays the demographic details for each pair. The demographic data, including their relationship with the remote participant, were taken prior the study from the participants.

Pair	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Age	27.5	43.5	27.5	24.5	29.5	25.5	28	26	23	25.5	23	27.5	31.5	19.5	21	19	19	23	21.5	36
Relationship	C	C	F	F	F	F	F	F	F	F	F	F	C	F	F	F	C	F	F	N
Familiar with robots	1.5	3.5	3.5	2	1.25	1.5	2	1.5	2.5	3	2.5	2	4	2	2.5	2.5	3.5	2	3	2
Familiar with computer Games	2	3	3.5	4.5	3.25	4	2	3.25	5	4	3	3.5	5	4.5	4	5	5	4	3.5	2.5
Video communication experience	1.5	1	2	5	5.5	6	2.5	7.5	2.5	15	10.5	4.5	11.5	6.5	3	9.5	1	5.5	3	1.5

Table 8: Demographic data

(Age: Mean values, Relationship: C= colleagues – F=Friends – N=None, Familiarisation values indicate 1 for low and 5 for maximum, Communication experience shows the average weekly hours users spent on video communications)

5.4.2 Procedure and experimental setup

Each participant was seated in front of a computer with an AIBO robot, and then started communicating with the other user located in a separate room using a combination of webcam and microphone through Internet conference software, Skype. Users were given approximately 5 minutes for each playing mode in order to familiarise themselves with the AiBone software (for each mode of interaction), and then continued with the study unless they needed more practice time in a specific mode. In order to consider the familiarisation factor for a specific mode, we counterbalanced the order of the two playing modes by allowing half (20 participants) of the participants to start with the conventional mode first and then progress to the Robot mode and the other half to start with the Robot mode and progress to the conventional.

5.4.3 Data collection

Each room was equipped with a second video camera, used to capture the behaviour of the user, the robot and their interaction. In addition, AiBone recorded a series of log files which contained all user input and game states such as the virtual character's position, local and remote AIBO internal states, game mode, date and time. Furthermore, each AIBO stores an internal log file into its memory card as it captures every event (e.g. petting history, ball visibility, executed behaviours etc.) with timestamps in order to analyse the user-robot petting history and robotic behaviours. Both log files have been used in our statistical analysis after they were extracted and imported into Microsoft Excel. At the end of each run, participants were given a questionnaire to fill in, which allows us to assess their game experience.

5.4.4 Methods

For the video data analysis we used Noldus Observer XT[14] to analyse and code user's behaviours. We used the following coding scheme for the videos:

i) Gaze

- Gaze at screen
- Gaze at robot

iii) Talk

Socially Oriented

- Speech to other User about AIBO experience

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[14] Noldus Observer XT behavioural coding suite (2009) http://www.noldus.com/human-behavior-research/products/the-observer-xt, Accessed Mar 25, 2011

- Speech to other User about something

else

ii) Smiles

Task Oriented

- Negative AIBO comments
- Positive AIBO comments
- Speech to the other User about game

The above coding scheme was used to statistically analyse the effects of participant gaze, smiles and speech relatively to participant enjoyment and preference (questionnaire data) during the game in both modes. From the video analysis we chose behaviours that characterise human-robot and human-human interactions. The gaze behaviour was chosen in order to evaluate the participants' perception on the game and generally on the proposed platform. This information reflects the time that each participant spent looking at the robot while playing the game and indicates how focussed and concentrated the participant was. Besides gaze, since smiles typically indicate a positive social cue towards the game and the remote participant, we also count the number of smiles shown by each participant in each gaming mode. We assume that smiling during the game reflects the participant's enjoyment while playing the game. Furthermore, according to Rashotte (Rashotte, 2002) smiles are considered a very strong social cue between humans in social interactions. Along with the smiles and gaze, we also coded speech and its nature (socially or task oriented) in order to measure the exchanged verbal social cues between the participants. The socially oriented speech was divided into 2 further categories, representing the number of times the participant talked to the other participant about his AIBO or about something else. Task oriented speech is coded when a participant talks about the game task while socially oriented is when he talks about non-game related matters. An example of task oriented speech is when the participants coordinate their movements in the virtual environment via speech in order to succeed in their task or comment about specific AIBO features and capabilities (e.g. “AIBO is too slow”, “AIBO helped me finding the bone” etc.). The task oriented speech was further divided into 2 categories, measuring the participant’s positive or negative comments about his robot which are directly related to the task, and speech about the game which most frequently concerned cooperation in the game. Finally, further to the video analysis and questionnaire data, the robot’s internal log files and the game log files have been used to extract information regarding the percentages of petting and ball visibility during the game.

5.4.5 Data analysis

Results from the questionnaire data were statistically analysed. The questionnaire data shows the median value of participant experience of cooperation and coordination between the participants in Conventional and Robot modes respectively, as well as the median value of the overall game experience on both modes. From the game log files we extracted the collected “bone values” (rewards) for each level and we also distinguished the collection method (individual or co-operative collection). Individual collection occurs when one virtual character finds and collects the bones on its own, whereby co-operative collection occurs when both participants cooperate to find and collect the same bones and are thus getting double points as described above in Section 5.3. By using this information we can assess the participants’ performance for each level and the degree of cooperation for both playing modes. Concerning the data collected from the robots we analysed the log files which captured the number of petting events from the participants and the percentage of ball visibility. We analysed the “petting value” as it is important to assess the interaction frequency between the participant and the robot. Since the robot runs in autonomous mode and executes certain behaviours, it requires feedback and input from the participant. The “visibility value” derives from the AIBO camera that tracks the provided pink ball and records the number of occurrences when the ball was visible for each game. It shows the participant’s performance with regards to controlling the AIBO in a sufficient way, i.e. understanding the concept of controlling and interacting with the robot.

In order to evaluate the video coding reliability, a trained secondary observer coded 20% of the videos (8 randomly selected videos out of 40 for both game modes) by using the same procedure as the original observer. The observations of the secondary observer were compared with the original observations using Cohen’s Kappa statistics (Cohen, 1960) in order to measure the inter-rater agreement (Gwet, 2002; Gwet, 2008).

5.5 Results

Firstly, we discuss results from the inter-rater agreement tests. Next, in Figure 43, we present the participants’ questionnaire results regarding cooperation and coordination between the participants and their overall experience of the game. In Figures 44 and 45 we present the game scores that each participant managed to achieve during the game. Figures 46, 47 and 48 show the Human-Robot Interaction derived from the video data and the robots’ internal log files. Finally, Figure 49, 50 and 51 summarise the social effects of an autonomous robot on human-human communication during their interactions with the AiBone system.

5.5.1 Inter-rater agreement

Table 9 shows the detailed inter-rater Kappa values. The values of the table show the proportion of agreements between rater 1 and 2 along with the Cohen's kappa coefficient value in order to check the reliability of the video coding. At the bottom of the table average values are shown for each column. The reliability analysis was performed with the use of a tolerance window of 1 second and aligned the observation times for accurate synchronisation. Section 4.5.1 in Chapter 4 describes the acceptable values for reliable video coding using the Kappa analysis. For this study, the average value of 0.65 falls into the range of good agreement between rater 1 and rater 2 therefore we consider our results reliable and acceptable. The Robot mode coding produced lower Kappa values between the inter-raters because in these videos participants also interacted with the AIBO besides the computer, and therefore, gazing on different objects was included in the coding and it produced a large number of time based events which were difficult to code accurately and precisely from both inter-raters (e.g. multiple gaze timeline events coded with millisecond accuracy). Results show that overall the inter-rater agreement is acceptable.

Participant - Mode	Proportion of agreements	Kappa value
14 - Conventional mode	0.78	0.62
14 - Robot mode	0.72	0.55
17 - Conventional mode	0.81	0.71
17 - Robot mode	0.76	0.64
25 - Conventional mode	0.94	0.78
25 - Robot mode	0.73	0.54
26 - Conventional mode	0.93	0.73
26 - Robot mode	0.71	0.54
35 - Conventional mode	0.92	0.79
35 - Robot mode	0.72	0.64
37 - Conventional mode	0.78	0.66
37 - Robot mode	0.79	0.62
40 - Conventional mode	0.91	0.64
40 - Robot mode	0.74	0.62
Average	0.80	0.65

Table 9: Inter-rater agreement and Kappa values

5.5.2 Users' experiences in the two playing modes

The following results present the users' experiences in the two playing modes:

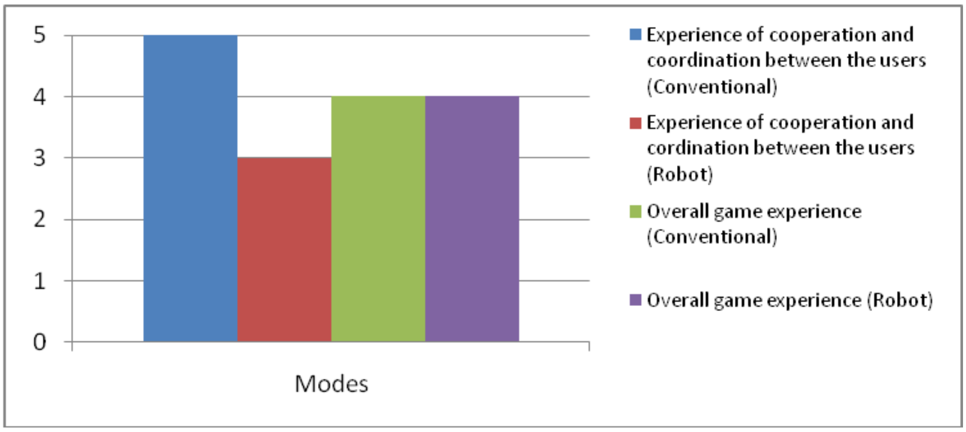


Figure 43: Results of questionnaire data for user experience in both modes

The overall game experience indicates the same user preference, based on median questionnaire values, for Conventional and Robot modes. On the other hand, the cooperation and coordination preference between the users is significantly lower in the Robot mode as calculated by using Wilcoxon's statistical test (Z=-4.802, Sig.=0.0001).

5.5.2 Total collected bones for both modes

The following two graphs show the scores of total collected bones by each user in the two playing modes.

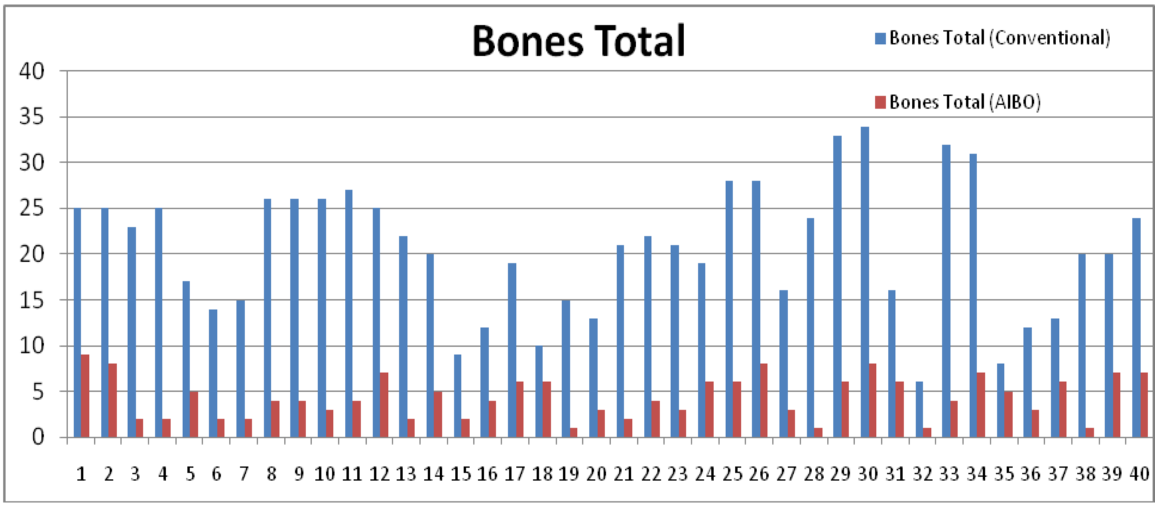


Figure 44: Total number of bones found for both playing modes

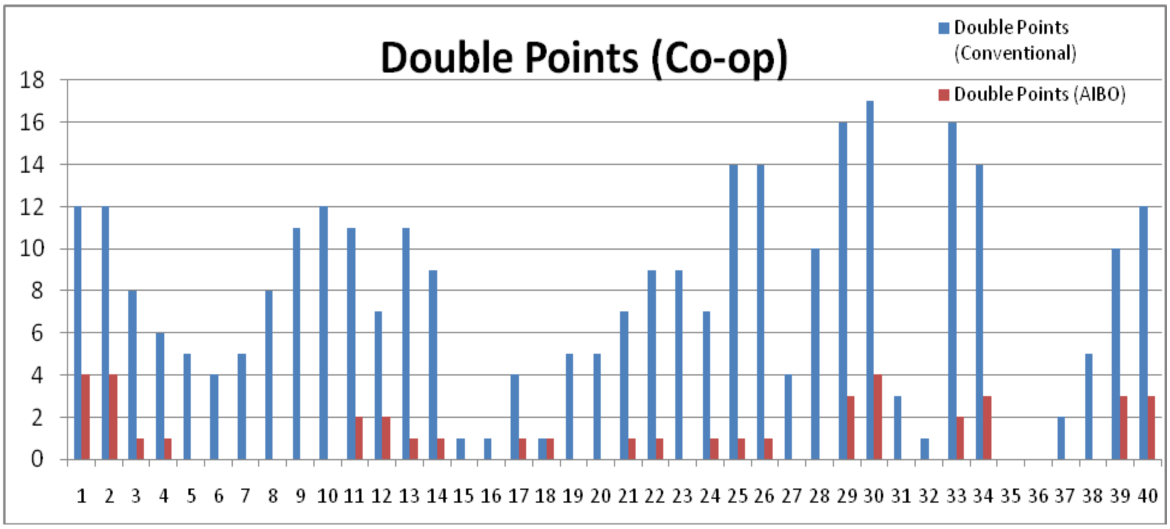


Figure 45: Total of double points gained from cooperation in both playing modes

In Figure 44 it is clearly shown that users managed to collect more bones in the Conventional mode than in the Robot mode and the results are significant as shown after a Paired Samples T-Test (Std Dev.= 3.142, t=25.863, Sig.= 0.0001). Furthermore, Figure 45 shows the differences between the collected double points (in cases where they cooperated) between the users, with statistically significantly higher scores for the Conventional mode (Std Dev. = 1.657, t=12.785, Sig. = 0.0001). There is also a high degree of correlation between the two modes, whereby users who managed to get high scores in one mode also got a high score in the other mode. A Pearson's correlation statistical test was conducted on the above results for both 'Total' and 'Double' collected points respectively and revealed a proportional significant relation among them (Total points: Pearson correlation= 0.933, Sig. (2-tailed) = 0.0001, Sig. at level= 0.01 and Double Points: Pearson correlation= 0.701, Sig. (2-tailed) = 0.0001, Sig. at level= 0.01).

5.5.3 Gaze at AIBO (percentages)

The following graph presents the total percentage of gaze at robot during the robot game mode:

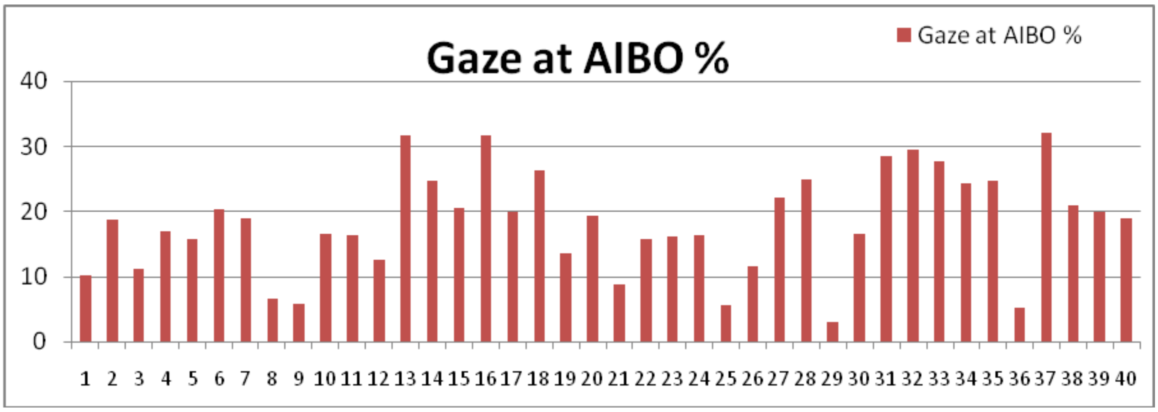


Figure 46: User gaze at AIBO in percentages

Users spent on average 18.21% of their time looking at the robot while playing the game. (Std Dev. = 7.72, Mean= 18.2, Min= 2.89, Max= 32.04).

5.5.4 AIBO ball visibility

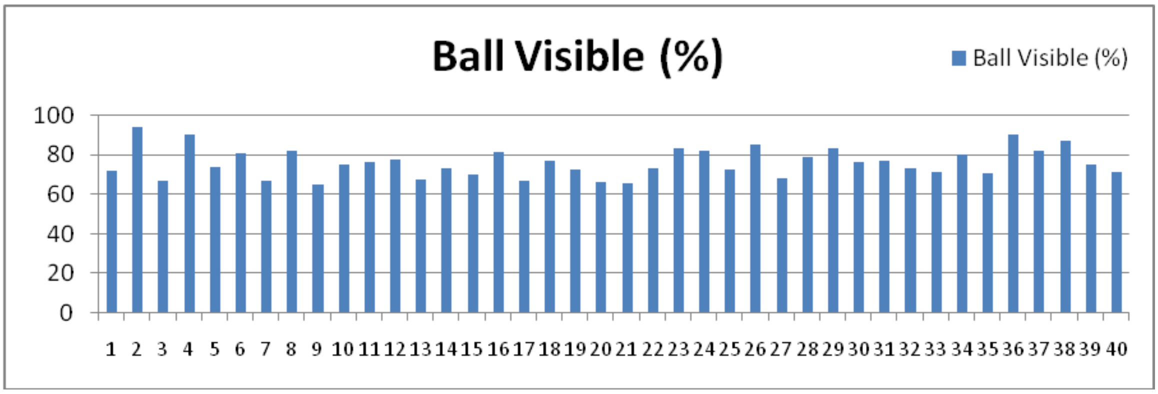


Figure 47: AIBO ball visibility percentages for each user

Figure 47 displays the percentages of time when AIBO managed to track the pink ball during each game. The data is derived from the robot's internal log files and is statistically analysed resulting in a mean value of 76.32% (Std Dev. = 7.34, Min= 65.5, Max= 94).

5.5.5 Number of robot petting behaviours

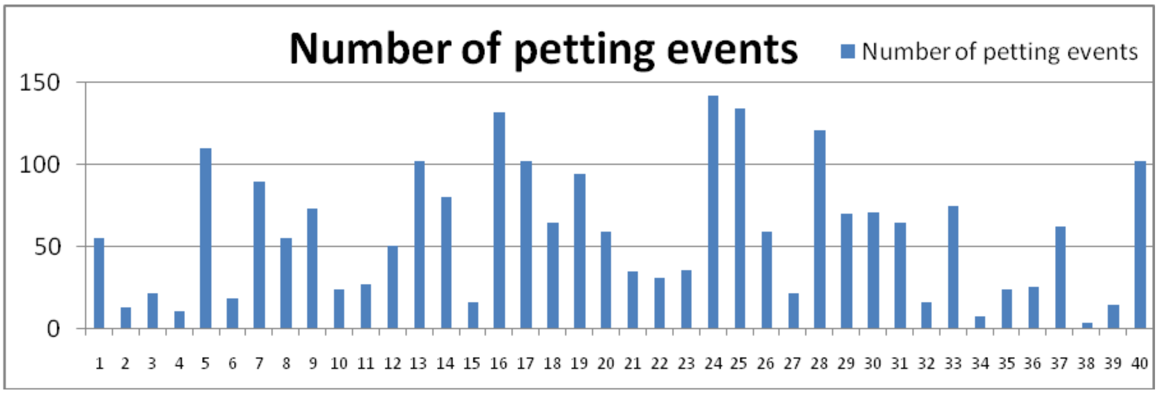


Figure 48: Number of petting the robot of each user in the Robot mode

Figure 48 shows how often users petted their robot dogs on the head or on the back sensors. This information has been extracted from the robot's internal log files and has been statistically analysed with a mean value of 57.95 (Std Dev. = 39.1, Min= 4, Max= 142).

5.5.6 Number of participants' smiles for both game modes

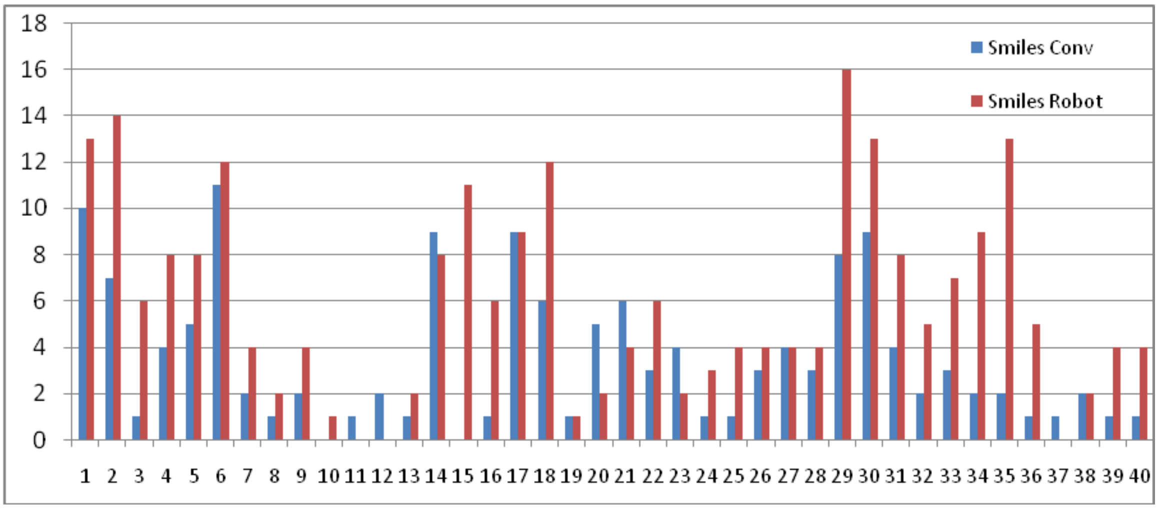


Figure 49: Participants' smiles for Conventional and Robot mode

Among a variety of social cues, the smiles between the users have been recorded, see Figure 49. A Paired Samples T-Test confirmed that users smiled more often in the Robot mode than in Conventional mode (Std Dev. = 3.282, t= -4.866, Sig. = 0.0001).

5.5.7 Non-task related speech between the users

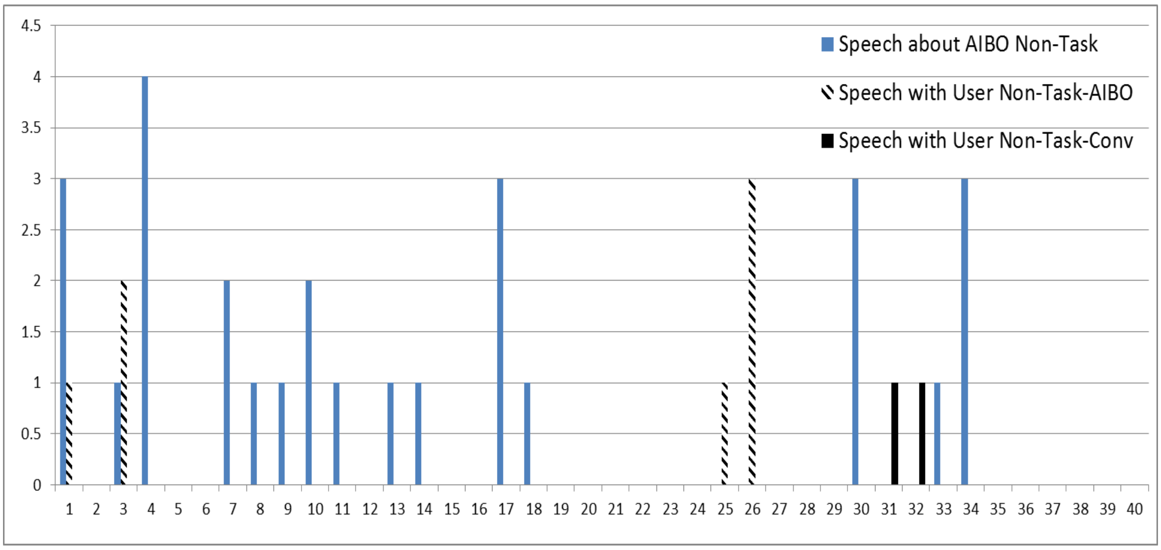


Figure 50: Speech with non-task content

Further to the smiles, which indicate social cues, speech between the users (Figure 50) with non-task content was also coded. In the Robot mode, users talked more frequently (37 times compared to 2 in the Conventional mode) about non-game related matters as well as sharing their experiences of the AIBO robot.

5.5.8 Task-related speech

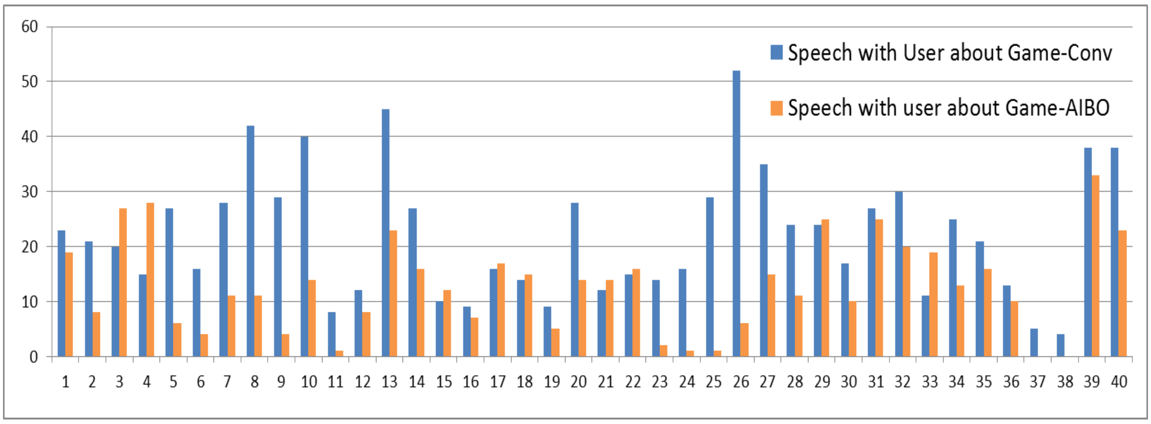


Figure 51: Task-related speech between the users for both playing modes.

The above figure represents how often users spoke to each other about game related matters. A Paired samples T-Test has been performed in order to validate our assumption that users talked more in the Conventional mode than in the Robot mode and the results are significant (Std Dev.= 11.73, t= 5.107, Sig.= 0.0001).

5.6 Discussion

The main focus of this study was to compare and analyse participant experience and preferences between two input modes in a cooperative 2-player game. Further to this question, we wanted to study the social impact of the two modes on the participants while communicating and playing the game remotely. However, results from the questionnaire and video observations confirmed that the task oriented nature of the game, as it was designed for this study, did not require the participants to express many social gestures and initiate social conversations.

Based on the questionnaire data regarding the experience of the cooperation and coordination between the participants, it is clearly shown (Figure 43) that participants preferred the Conventional mode for the given task, thus not supporting our initial hypothesis H1. However, further inspection of the results provides clues of why our initial expectations were not met. It appears that in order for the participants to show an ease of use similar to that of the conventional mode they require extra time to experiment and get familiar with the novel robotic controls, although they were given approximately five minutes prior to each gaming mode. An autonomous robot such as the AIBO is considered a novel and complicated device from the participants' perspectives for applications that require immediate control and coordination through an interface, as confirmed by participants' comments on their interaction with the AIBO. Comments included: "I liked the novelty of using a robot to play the game" (participant 3), "It was interesting to use a different interface" (participant 21), "It was more interesting than a traditional keyboard" (participant 16), "I was too busy trying to control robot to interact with the other participant" (participant 9), "very interesting!" (participant 7), "robot was hard to control and focus on the screen - Difficult" (participant 5). Participants found it hard to control the virtual character in time in the Robot mode, and as a result the human-human game coordination was difficult and insufficient. Furthermore, the pre-defined time limit of each game level seem to have encouraged the participants to search for bones individually and competitively, and for that reason participants preferred the conventional keyboard and mouse input devices which are easy to use and they were very familiar with, and thus allowed them to perform the task quicker. On the other hand, the overall game experience values indicate that the participants showed the same preference for both Conventional and Robot modes. This value represents their overall experience after they finish the game in both modes including their interactions with the robot. Consequently, even though the participants found the control of the virtual character more challenging, and maybe sometimes annoying, in the Robot mode, the robotic behaviours, their interactions with the robot and the sharing of common experiences with the robot among the participants, balanced the overall evaluation of the system by the participants. In summary, the questionnaire results indicate a preference towards the Conventional mode regarding the control of the interface and human-human cooperation in the computer game, however, the presence of a robot positively affected the overall remote communication experience during the game. A robot appearance such as an AIBO (zoomorphic shape) might have had a novelty effect on the participants, therefore, further investigation has to be done in order to verify the results. Long-term studies would also be able to shed further light on these issues.

Further to the questionnaire data, figures 44 and 45 showed the total number of collected bones of each participant between the two playing modes, which supports our previous argument that game oriented tasks are more difficult to achieve with robots. The conventional input devices such as the keyboard and the mouse more directly controlled the virtual character and therefore, the moves required in the computer game were performed faster, allowing participants to scan the game levels for bones more efficiently in comparison to the Robot mode. Figure 45 showed the difference between the two modes in terms of cooperatively collected bones where the Conventional mode scored significantly higher than the robotic mode. In the Robot mode, participants found it more difficult to quickly move their character in time (as stated before), and therefore, they preferred to continue looking for hidden bones individually by searching separate places on each levels.

Figures 46, 47 and 48 displayed the interaction patterns between the participants and the robots. Figure 46 showed the percentage of gaze at the computer screen in the Robot mode which has been extracted from the video observations. During the communication, participants were looking either at the screen or at the robot at one given time. The mean gaze value for the participants is 18% which shows how little time they spent looking at AIBO during the game in the Robot mode which is low compared to the gaze at the screen (82%). The above conclusion supports what initially differentiates conventional controls from robots. In particular, the majority of conventional control devices have been designed to offer immediate haptic feedback whilst autonomous robots require continuous human input in order to perform accordingly. Furthermore, the navigation of a virtual character through an AIBO entails ball tracking which consequently requires the attention of the participants to lie with the AIBO. This observation suggests that participants found it confusing to focus on two different objects while performing a game oriented task on the computer especially when there is little familiarisation with the provided controls. The limited gaze on the robot may affect participant’s perception regarding robotic behaviours and robot control as required by the game. Thus, it might have been difficult for the participants to fully understand the principles of Human-Robot Interaction afforded by the game. This argument can be supported by results from the robot’s internal ball tracking log files. This log file captured the number of times that the pink control ball was in sight, thus allowing the robot to control the game. Figure 47 pictured the number of times that AIBO successfully tracked the provided pink ball during the game in percentage values. The average ball visibility is 70% during the game which is generally low for sufficient game control since the primary input to the robot is the provided pink ball. Theoretically, ball visibility should be very close to 100% for continuous virtual character control like in the Conventional mode where participants persistently press the keyboard/mouse buttons. Figure 48 depicted the number of times participants petted their AIBOs during the game. The number of robot petting was also quite low which led to poor game performance because of the continuous triggering of the robotic boredom behaviour – the AIBO was running in autonomous mode which requires participant attention whenever the boredom internal state drops. On every execution of the boredom behaviour of the robot prevented the participant from continuing to play for a certain amount of time until the participant ‘satisfied’ the robot’s internal states. The robot’s autonomous behaviour execution did not seem very suitable for such games which require participants to act fast and efficient (rather than ‘social’) in order to achieve better game performance.

The above results indicate the importance of selecting the appropriate medium of interaction for specific tasks. Specifically, our results suggest that an autonomous robot is not necessarily the best option for replacing conventional and accepted interaction devices in task-oriented collaborative game context, at least not in short-term interactions as used in this study.

Nevertheless, Figure 43 showed that participants overall liked the game and communication experience that the Robot mode offered as much as the Conventional mode. This was further analysed considering speech and smiles between the participants who played the game in a pair. Figure 49 showed the number of times participants smiled at each other while playing the game in both modes. Smiling provides a positive social cue to the other participant and it is usually perceived as an indication of enjoyment while the participants communicate visually. In the Robot mode, participants might have got more excited when they collected points because it was more difficult than the Conventional mode, and thus they were more satisfied. The recorded smiles for both modes clearly show that participants smiled almost twice as much in the Robot mode compared to the Conventional mode. Concerning speech, Figure 50 clearly showed that participants talked more frequently about non-game related matters as well as sharing their experiences about the AIBO robot, compared to the Conventional mode. The result that not every participant talked about non-game related matters might have been caused by the fact that the game was designed with a strong focus on task achievement. Further to this, the time limit for each level complicated the task and stressed the participants to find the bones in time - thus not leaving them many opportunities to socialise through the game. Figure 51 presented the task related speech where participants generally spoke with the same rate in both modes with no significant fluctuations on most occasions. On average, in the Conventional mode participants talked more than in the Robot mode regarding task related matters, probably because the difficulty of controlling the virtual character in the latter mode discouraged the participants to cooperatively search for bones within the time limit for each level, and therefore, they sought for the bones individually (resulting in less task related conversations).

Generally, with this specific game, participants in the Robot mode showed more social cues during the game. In summary, we demonstrated that an autonomous robot can be used for remote human-human communication in the context of a collaborative game; but when it is compared to a Conventional mode of interaction, participants consider it less suitable to finish the given task in time. Participants are very familiar with the Conventional mode (keyboard and mouse) as shown by demographic table while on the other hand, an autonomous robot is new technology to them. Also, the robot had not been designed specifically for the purpose of replacing conventional interface devices but to allow them to share human-robot experiences and increase their social bonding. However, although AIBO does not offer the same performance in such task oriented games compared to the Conventional mode, it increases the social interactions between the participants thus offering a new communicative experience to the participants. The results of this study indicate that an autonomous robot has the potential of enhancing human-human experience in remote communications and consequently make it more enjoyable when the purpose of the interaction is less competitive and task oriented and more socially oriented. Additionally, based on the significant results shown above and along with the participants' questionnaire data regarding game mode preference, it is shown that although the participants preferred the Conventional mode for playing such games, that does not mean that the participants did not actually enjoy the overall communication experience in the Robot mode. Bringing a robot to such 2-player computer games inevitably makes the game task more difficult and more effortful to the participants since they have to cope with and focus on two different objects at the same time i.e. controlling the game character and providing input with the autonomous robot.

5.7 Conclusions

This study focused on enhancing the remote communication between two participants with the addition of an autonomous robot as a social mediator and gained positive results in regards of social cues used in human-human communication. We added an interactive and collaborative computer game to the communication channel between the participants in order to enhance their interaction experience during the video call. In this study we analysed participants' behaviours and reactions with our system and explored their preferences during the remote communication. We analysed questionnaire data, robot and game log files and videos in order to answer our research questions and expectations. The analysis was based on our previous setup from Chapter 4 where we identified suitable methodologies for analysing human-robot and human-human interaction on remote communication. Results showed that participants found the Robot mode exciting although sometimes they would get frustrated because of the difficulty that the new technology added. However, we also provided evidence that participants expressed more social cues and shared their game experiences through the robot with each other. Additionally, results showed that it is very difficult for participants to familiarise themselves quickly with new technologies when they can perform the same task more efficiently with conventional devices. While long-term use of new technology may increase the efficiency of how participants operate the robot, it is likely that for standard tasks such as controlling a computer game character on a screen, conventional interfaces may be superior in terms of performance. Finally, we also discussed the factors that caused participants’ frustration especially for controlling the robot that need to be carefully considered and addressed when designing a human-human communication tool with robots as social mediators.

This exploratory study informed us about the human-robot and human-human interactions in remote communications with robots as social mediators compared with a traditional method of interaction. The findings and the participants’ feedback gave encouraging evidence for using autonomous, interactive robots as social mediators for distant communication. While the robot’s dog-like appearance might have led to a novelty effect in our experiments, questionnaire results supported that AIBO robots are enjoyable from the participants since in this mode the number of exhibited social cues is higher than in conventional mode and the rating regarding the overall game experience is above 3 (Neutral). Furthermore, the autonomous level of the robots affected participants' attitude towards the robots and facilitated them to express more social cues between them. For that reason, we believe that a richer repertoire of embedded dog-like behaviours and impulsive AIBO actions will enhance participants' perception of interacting with an autonomous intelligent robot thus encouraging them to share their personal experiences. Additionally, results showed the importance of selecting an appropriate medium of supportive interaction through the computer interface, in our scenario the computer game, as task oriented applications require a lot effort from the users. Lastly, the utilisation of an appropriate methodology as described in Chapter 4 (section 4.7) for analysing human-robot and human-human interaction allowed us to perform the required data analysis extracting significant correlations that helped us answering our research questions (RQ3). Furthermore, this specific game scenario which added a competitive task, required some additional measurements in our current methodology in order to extract comparable results between the two gaming modes. Thus, this 'enhanced' methodology could be used in future experiments covering a wider field of remote human-human communication mediated by robots. Consequently, based on these findings, we will use a non-task oriented application to support the human-human and Human-Robot Interaction in our future work.

These results may also have implications for other application areas of autonomous and "social" robots, beyond human-human remote collaborative game contexts. Specifically, we hypothesise that the more task-oriented, or competitive the chosen interaction scenario is in human-human collaborative settings, the more participants will prefer the most "efficient" and easy to use interface, in particular those interfaces that they are already familiar with.

Using robots as companions or social mediators is a growing area of research, but, as this study has shown, one cannot automatically assume that adding a robot will improve the task or interaction experience. Instead, one carefully needs to investigate experimentally whether the introduction of a robot will actually benefit the particular task performance or the participants' experience of the interaction. Such a systematic assessment could lead to future recommendations for the design of interaction scenarios involving robots and people.

5.8. Chapter summary

This chapter studied the effects of an autonomous robot on human-human remote communication in comparison with a Conventional mode of using keyboard and mouse. We developed a platform that supports communication either through a robot or by using conventional devices. Forty participants (20 pairs) involved in this comparative study. Each pair of participants utilised both the robotic and the conventional devices to play an interactive game while they communicated using video conference software. Instruments used in this study include questionnaires, video observations and log files for the game and the robots' states. The participants' comments suggest that although enjoyment from the use of AIBO as a social mediator was present, gameplay engagement would benefit from further familiarisation with the robot for an ultimate user experience. As our human nature suggests, further use and familiarisation with new devices results in realising and utilising the full potential of them in time. Improvement showed that it is difficult for users to familiarise themselves quickly with the robot while they can perform the same task more efficiently with conventional devices. However, we provided evidence that users expressed more social cues and shared their game experiences with each other through the robot. Finally, we discussed the factors that caused users' unfamiliarity and even frustration while controlling the robot. We believe they need to be carefully considered and addressed when designing human-to-human remote communication systems with robots as social mediators.

Chapter 6: A long-term comparison study for robot and non-robot mediated remote communications

6.1 Introduction

Our previous studies (see Chapter 4 and Chapter 5) showed multiple positive results regarding remote communication enhancement. Generally, participants enjoyed the presence of robots in their communication channel, as they found them entertaining due to linked internal states and multiple dog-like behaviours and helpful in their interactions as the robots guided the users in order to find hidden objects in the virtual environment (in AiBone platform). Furthermore, the interactions that robots offered to the participants, along with the capability of remote tangible cooperation, helped them to increase their games scores as the pointing behaviours guided the users closer to the hidden object (AiBone platform) and managed to achieve an efficient in game navigation (AIBOcom – 'mirroring' mode).

However, although participants preferred the robot mode in comparison with the conventional mode in our studies, further investigation of their results and written comments revealed that the communication platform was task-oriented inasmuch that both AIBOcom and AiBone were based on cooperative games, which mainly produce measurable results derived from the participant's ability to utilise the proposed input devices efficiently. The AiBone study revealed that although participants found the robot mode more enjoyable than its conventional counterpart, they also stressed that the latter mode allowed them to cooperate more efficiently and therefore with less frustrations during the game. As the Chapter 5 described, participants are generally more accustomed to using keyboard and mouse devices than robots, and furthermore a conventional device offers very quick and direct control of a game due to its simplicity. Hence, we decided to use a non-competitive task in our third study (AIBOStory), which was based on storytelling. In AIBOStory, participants can cooperate and share stories through a graphical interface and at the same time utilise the robots in line with the story told. In order to allow the participants to feel more engaged with the system, we decided to extend the duration of each session to 13 minutes and increase the number of sessions to ten, which would allow us to extract more accurate results about participants' preferences and also eliminate the potential technological novelty effect of the robots, which usually wears off after short periods, as previous studies have shown (You, Shen, Chang, Liu, & Chen, 2006). Furthermore, we decided to use multiple sessions in order to let the participants develop and establish their social engagement through stories with continuity and social meaning. These stories would enhance participants' experience and therefore encourage them to seek it again, thus becoming self-motivating. Furthermore, since participants would be involved with multiple sessions, we decided to implement and apply a basic memory architecture in the robot, in order to offer various intelligent choices to the participants and to enhance its autonomous behaviours and capabilities. We believed that memory architecture in the AIBO robot would help the participants to perform in a shrewder manner and make the experience far more enjoyable during the communication process. Lastly, we decided to give more 'freedom' to the robot with regards to communication, so that it could take part in the story developing jointly with the users and autonomously when the robot's internal states take over.

6.1.1 AIBOStory - Introduction

The AIBOStory communication platform offers a dynamic graphical interface to users, enabling them to share a story by selecting various meaningful elements to comprise a tale, while at the same time an autonomous AIBO robot companion reacts dynamically and autonomously according to the context of the story. The user interface is designed to offer various sound and visual effects in line with the current active framework of the narrative. Furthermore, users can add custom messages, making it more personalised, unique, random, flexible and fun.

6.1.2 Narrative

AIBOStory focuses on the development of a distant story between participants based on the narrative and more specifically on the emergent narrative (unscripted narrative (Aylett et al., 2006)). Narrative is a presentation of a story (Abbott, 2002) in which the story remains the same but the presentation might vary each time the tale is told. A story can be defined as a series of events that contains time-based entities through which humans develop a predictable, meaningful and consistent world (Abbott, 2002; Bruner, 2003; Schank, 1995). Narrative can help an individual to gain a better understanding of surrounding behaviours and interact with them consistently, as a sense of self is developed. It also provides a structure for people to share social knowledge and experiences in social groups (Linde, 2001), while Dautenhahn and Schank stress that narrative can serve as an everyday communication function (Dautenhahn, 2002; Schank, 1995).

Narrative in communication can engage and enhance the interaction between two distant users, if the story follows certain rules such as flow and logical sequence (order of events). Flow occurs when humans are highly involved with the activity of story writing and it offers an enjoyable experience (Csikszentmihalyi, 2000). Therefore, the person who experiences flow in his story will seek it again in the future, as he becomes self-motivated, and a story that makes sense and is created with a series of logical events is considered an enjoyable story that is easy to follow and understand, especially in AIBOStory, where two people construct a shared story.

Emergent narrative has much potential for enhancing distance communication, entertainment games and game-play, as well as an impact on the design of these systems (Louchart & Aylett, 2004). Furthermore, it can help with story construction in order to make it more enjoyable and understandable to users by contributing events based on what the story requires. An example of an algorithm that supports the emergent narrative approach is the late commitment process (Swartjes & Vromen, 2007), which allows virtual agents to contribute to the story in line with events that the story necessitates. The late commitment process allows virtual characters to choose material intelligently, based on the development of the story, and gives them more flexibility in their reasoning processes (Swartjes, Kruizinga, & Theune, 2008). In addition to the narrative genre, role-playing games allow users separated by distance to engage with the system and collaborate in order to achieve a common task in accordance with the game rules. Tychsen, Hitchens, Brolund and Kavakli proposed the ‘Game Master’ (GM) concept, which is a set of functions for these games (Tychsen, Hitchens, Brolund, & Kavakli, 2005) consisting of several functions such as narrative flow within the game, thus providing dynamic feedback for players and maintaining momentum. Likewise, it is responsible for enforcing game rules and ensuring that all players are aware of them, while it also introduces multiple challenges and facilitates inter-player communication. Lastly, it is responsible for creating a virtual world and filling it with virtual elements required for the game. The GM concept encourages players to practice storytelling in games more dynamically and enjoyably, as the provided environment is more tailored and reactive to specific players.

Example of narrative integration on remote communication enhancement projects can be found in section 2.5.1 of Chapter 2 (cf. Raffle et al., 2010, Freed et al., 2010).

6.1.3 AIBOStory system

AIBOStory utilises two AIBO robots that handle the Human-Robot Interaction. The AIBO robots (one for each user) are integrated with the system and execute behaviours synchronously based on selected story elements. Moreover, users can interact with the AIBOs and trigger various autonomous actions that will affect and contribute to the story and which have been carefully developed to avoid possible negative effects towards attitude and trust (Jameson & Schwarzkopf, 2002). However, Human-Robot Interaction have to be developed and investigated carefully in order to obtain positive results from touch via physical contact with users (Cramer, Kemper, et al., 2009). Human-Robot Interaction were implemented bearing in mind both robot and human perspectives for robotic "sociability" (cf. (Bos et al., 2002; Breazeal, 2003)), and as such we hypothesise that the AIBO robot will help to maintain and enrich users' relationships over distance (Dautenhahn, 2007). Vitally, each robot is an autonomous system with its own set of behaviours, sensing abilities and internal variables ("needs", cf. (Avila-García & Cañamero, 2002; Meyer & Guillot, 1991)) and the user is expected to interact with it like a real pet in order to regulate these dynamic changes. During the communication process, users can trigger the AIBO's behaviours by selecting appropriate elements, or else AIBO can autonomously execute dog-like behaviour (cf. (Kahn et al., 2004; Kerepesi et al., 2006)) controlled by the robot's internal states. Furthermore, AIBOStory offers a personalised suggestions list to the user, based on recent actions and the repetition of events, but it is shown only when the robots are active in order to remind users of their previous choices and to help them choose the next element of the story more wisely. AIBOStory also offers the option not to use the robots or the suggestions feature during communication and instead to use only the graphical user interface, as this allows us to compare users' experiences associated with the use of the robot.

6.1.4 Memory in AIBOStory

AIBOStory is based on an interactive storytelling scenario whereby two users interact with each other by constructing a shared story across geographical distance using their computers and AIBOs. Similar projects have used this type of interactive approach in order to provide a virtual environment and multiple virtual agents capable of acting out a story in an interactive manner (Cavazza, Aylett, Dautenhahn, Fencott, & Charles, 2000; Mateas & Stern, 2003). However, since human interactions are mainly unpredictable, the characters' behaviours should not be scripted beforehand; instead, for long-term human-robot or human-computer interactions, the system must be capable of remembering past experiences and utilise them in order to provide meaningful behaviours and actions accordingly.

> "You have to begin to lose your memory, if only in bits and pieces, to realise that memory is what makes our lives. Life without memory is no life at all, just as intelligence without the possibility of expression is not really intelligence. Our memory is our coherence, our reason, our feeling, even our action. Without it, we are nothing". Luis Buñuel. Spanish director, 1900-1983

Long-term robot-enhanced communication technologies could benefit greatly from various memory architectures that allow the robot and the system to become more personalised (remember) as a result of users' routines. Memory should exist in intelligent agents and robots, particularly in applications that require the development and maintenance of relationships with humans. Human relationships depend mainly on past experience, so for the same reason robots need to support memory architectures in order to create meaningful and personalised relationships with their human counterparts. Human memory is broken down into two types, the long term and the short term, the latter of which is responsible for storing information for very short periods of time before they get dismissed and is also referred to as working memory. Long-term memory is responsible for storing, managing and retrieving important information and is divided into three categories – explicit, implicit and autobiographical. Implicit memory is responsible for automatically storing information for actions such as bicycle riding, and explicit memory comes to the fore when a person makes a conscious effort to learn and remember something such as names or cities. Finally, autobiographical memory recalls life experiences and is further divided into episodic – deeply ingrained general facts that are easily recalled such as days of the week – and semantic – explicitly described and explained facts such as the decoration of a house – memories.

Theoretically, long-term memory architecture allows robots to “remember” significant events that will help them to communicate and interact with humans more naturally and realistically. The importance of long-term memory is supported by several research results (Breazeal, 1998) that show loss of interest on the part of humans when robots are missing interesting behaviours developed from long-term Human-Robot Interaction. There has been a great deal of research in the field of Artificial Intelligence regarding how agents adapt to the environment (Ho, Dautenhahn, & Nehaniv, 2008) and develop relatively short-term relationships with humans (Fujita & Kitano, 1998b; Kanda, Hirano, Eaton, & Ishiguro, 2003; Lewis, 2003). However, little research has been undertaken on how a companion agent creates a long-term relationship with humans, and in particular how robots could use this experience to help two users maintain and enhance their relationship whilst located far away from each other. Furthermore, the robot’s memory can be used to allow the robotic companion to learn user’s preferences and adapt to his interaction patterns.

AIBOStory is enhanced by two separate memory modules, one in the robots and the other in the interface platform, which is called the “suggestion list”. The suggestion list utilises an activation-based selection algorithm based on the recency and repetition of events (Nuxoll et al., 2004, 2010) and it was implemented to offer participants a selection of predefined events based on the choices they made in previous sessions and interactions. In addition, the AIBO robots are equipped with another memory algorithm that captures and ‘remembers’ the average pressure of the participants’ petting, and they then use this information to affect various internal robotic states (intentions). These two memory algorithms are utilised by the participants in half of the total sessions, in order to compare the importance of memory for long-term communications. Furthermore, the implementation of a memory architecture that is embedded in such a social mediator robot allows it to adapt to the user’s preferences for a more natural human-robot communication that can maintain a good level of engagement.

Users usually lose their interest in robots – and generally in new technologies – after some time, as what they consider ‘interesting’ or funny at the beginning of their interactions ends up ‘annoying’ and ‘boring’ after a while. Consequently, a robotic companion or any new technology that directly interacts with users must be capable of adapting to their preferences and attitudes while simultaneously responding accordingly to keep their interest levels high. Additionally, past experiences of a computational autobiographic memory model (Ho, Dautenhahn, & Nehaniv, 2006; Ho & Watson, 2006) would be beneficial for maintaining long-term social relationships (Ho et al., 2008), as artificial memory will help such systems to adapt to new circumstances and make predictions for situations, which in turn will allow them to generate suitable behaviours. Furthermore, it will allow the systems to act and react consistently with humans, thus demonstrating an artificial “personality”, which is very important in social communications (Dautenhahn, 1998).

Memory plays a very important role in developing human personality, as it controls behaviour and influences mood (Carver, 2005). Since its capabilities have proven beneficial for human relationships, researchers have tried to integrate the same memory techniques into artificial embodiments and agents (Ho, Dias, Figueiredo, & Paiva, 2007). Ogino et al. (Ogino, Ooide, Watanabe, & Asada, 2007) developed long-term episodic memory for a virtual robotic platform, in order to affect generated emotions accordingly and to ultimately enhance Human-Robot Interaction. Similarly, Brom et al. (Brom, Pešková, & Lukavsky, 2007) created a virtual agent with episodic memory capable of storing everything from its surroundings, in order to use these data for the purpose of storytelling. This specific memory algorithm included a ‘forgetting mechanism’ to truncate memory data by deleting records which had less emotional strength than others. Similar projects have used other more sophisticated memory algorithms, such as the ORIENT project (Lim, Dias, Aylett, & Paiva, 2008) which used the FAtiMA (Dias & Paiva, 2005) model for storing and retrieving memory elements. ORIENT is an educational role-playing game for social and emotional learning in virtual environments. It uses the FAtiMA memory model to retrieve past experiences from memory and then employs them in order to react in a more sensible manner in future situations. Researchers have also raised the ethics issue on robot companions with artificial memory capable of remembering sensitive information (Vargas et al., 2009). In this study, researchers proposed a forgetting mechanism to filter out any non-desirable human information to which a robot could have access.

A pilot study, consisting of five pairs of users (10 participants) and conducted prior to the long-term experiment, was carried out to evaluate the proposed system’s acceptance and its use. The main study was conducted through 10 pairs of participants (20 participants) to compare their preferences between a robot mode utilising a memory feature and a non-robot mode. Consequently, during the experiments we collected data including multiple questionnaires from different sessions, demographic forms and logged data from the robots and the system.

The chapter is organised as follows. Section 6.2 presents the key research questions and expectations. Section 6.3 describes the AIBOStory system and section 6.4 the experimental setup. Section 6.5 presents experimental and statistical results, while section 6.6 discusses and analyses the results. Lastly, this chapter ends with a Conclusion section, which includes an analysis of the results of the experiment and ideas for future research and development of the AIBOStory.

6.2 Research Questions

Since our main goal was to conduct a long term study and identify implications of participants' exposure to the robot and the system, initially we performed a pilot study in order to evaluate and receive feedback on the system's design and interface with a small number of users (10 participants) and used a questionnaire based on the Unified Theory of Acceptance and Use of Technology (UTAUT)(Davis, Bagozzi, & Warshaw, 1989).

Our main research question for the pilot study was:

Will the users accept remote, narrative and robot-enhanced communication in the proposed system?

Besides the acceptance of technology question, we also wanted to identify whether the participants found the system, including the tablet computers, comfortable to use. We expected participants to be very comfortable during their communication with the tablet computers because they could better focus on their objective (communication and robot interaction) without handling separate input/output devices used for desktop computers.

In the main, long-term study we wanted to address the following research questions:

R3Q1: *Would users overall enjoy the AIBO robot in repeated communication over several sessions using AIBOStory?*

R3Q2: *Will the users enjoy the robot's behaviours integrated into the AIBOStory system compared to not using any robot?*

R3Q3: *Will users utilise a memory feature in their communication that will remind them with their previous choices and sessions?*

We anticipated that users will find the robot mode more enjoyable than the no-Robot mode thus prefer it for their communication. An interactive medium such as the AIBO could offer a new experience to the users and allow them to collaboratively explore it with the help of the proposed system. Furthermore, we expected users to become familiar with the memory feature over the sessions, which helps them choose a desirable element based on their previous selections. We believed that as the users interact with the system and the enhanced the memory feature, they would use it more often to collaboratively create stories. Finally, we anticipated that users would enjoy the Human-Robot Interaction that the AIBO robot offers as part of their communication. Moreover, since AIBO was directly involved with the story elements, it was important to us that users would enjoy the system integrated with the AIBO as an entity rather than AIBO as a separate autonomous device detached from the system.

6.3 System description

Figure 52: System architecture of AIBOStory

AIBOStory (Figure 52) is a graphical remote communication system that allows two or more users to collaboratively create and share stories from distance along with traditional video conferencing software, Skype, which handles the voice and video communication. It consists of a GUI (graphical user interface – Figure 53), a local server (Figure 52) and a connection library that handles the synchronisation with the robot. With this software, users are able to share stories and interact with each other with the help of their robots. The GUI supports both desktop computers and tablet PCs and it adjusts the interface to the provided resolution. Users share a common user interface and contribute to a story by taking turns. The interface offers a fixed amount of pre-written elements (bottom of Figure 53) that are grouped into 3 categories: ‘AIBO related’, ‘Scene related’ and ‘Location related’. Apart from the fixed elements, the users can also type in their own sentences and use them in the story (custom story elements). Every chosen element is automatically placed in a row on the screen, which creates a sequence for the story. Additionally, after each user selection, the system provides a list of linking words to select a matching sentence for the forthcoming element of remote user.

AIBOStory is a very expandable platform as it supports multiple story schemes that could be easily imported using a folder that contains various background images and ambient sounds, sound effects and other elements.

One day me and my dog... my dog got excited ...and... my dog pointed down ...and... my dog got bored ...and...
my dog pointed down ...and... it was getting dark . Then... we went to park . Then... my dog started diggin
my dog got excited ...and... my dog got sad . Then... my dog walked fwd . Then...
my dog got excited ...and...

Figure 53: The graphic user interface of the AIBOStory

The server application runs on every machine and connects with the rest of the available servers and creates a Peer-to-Peer network. It also handles the communication between the interfaces and stores various information such as log files and memory data. The server also handles the communication with the robot library in order to activate robot behaviours according to the incoming data.

AIBOStory offers two interaction modes:

Non-Robot mode: In this mode users interact only with the computer devices and they neither see nor use the AIBO robots. Depending on the group from which users select the elements (AIBO, Scene or Location related), each category is assigned a different function (Figure 53 – Bottom). Some of the AIBO elements are linked with sounds that both local and remote users can hear immediately after the selection e.g. barking sounds. Additionally, users can select the customised story element where they can write their own sentence and publish it in the story (Figure 53- Bottom left –Question mark element). Similarly to the AIBO elements, a linked sound effect might play back depending on the keywords the user types in. The scene related elements produce sounds related to the environment such as wind or sea. Finally, the location related elements allow the users to select a new location for their story such as forest, beach etc. which changes the background image of the story. Every location is linked with a unique background picture and ambient sounds. Furthermore, every location lists and offers different elements to the users that are directly related to the location such as ‘swimming element’ in the ‘Scene related’ group when beach location is selected (see table 10 for element functionalities). Next to the category buttons, a label informs the users about their current chosen location while on the right side another label reminds them about their turn. Interface features that are specific to the robot’s behaviour (e.g. the Suggestions balloon type list, energy and mood progression bars) are not visible in the non-robot communication mode.

Groups	Functionality in AIBO mode	Functionality in No-AIBO mode
AIBO related	Behaviour execution in AIBO	Imaginary behaviours on story
Scene Related	Behaviour execution in AIBO on some elements + Sound effects on computer	Sound effects on computer
Location Related	Background picture and ambient sound change on computer + New elements	Background picture and ambient sound change on computer + New elements

Table 10: Functionalities of elements according to groups

Robot mode: This mode is similar to the non-robot mode but with the addition of an AIBO robot given to both users who remotely communicate via AIBOStory. AIBO is placed next to the users while they are sitting comfortably on short ‘bean bag’ type chairs in order to be closer to the floor where the AIBO moves freely. AIBO robots run in a ‘pet-like’ autonomous mode and over time they get ‘bored’ or ‘tired’. It is due to the fact that each AIBO has two internal variables named ‘boredom’ and ‘tiredness’ which get affected by time and the user’s touch, trying to mimic the behaviour of a typical pet. These variables are shown to the user within the interface by utilising two progression bars that change colour according to the state of the variable (e.g. red when close to 0 and blue when in the medium range).

AIBO has three pressure sensors on its body, one on the back, on the head and a simple on/off sensor on each paw. During the communication, both users have to interact with their AIBO by petting them on the sensors which in turn, influences the internal variables. When the internal variables reach a certain threshold, both AIBOs execute a predefined behaviour and at the same time they select a related AIBO element which is linked with the actively triggered behaviour. The ‘automatic’ element selection prevents the user from selecting his preferred element and he loses his turn. Therefore, users are encouraged to provide attention to the AIBO in order to keep its internal variables balanced and prevent it from unwanted frequent and unexpected contributions to the story which might cause frustration to the user. In this mode, every time a user selects an AIBO element from the list, both local and remote AIBOs execute the particular behaviour and, depending of the duration and the type of the behaviour, the internal variables are being affected accordingly (Table 11). Additionally, several of the ‘Scene related’ elements are linked with AIBO behaviours and they are called as soon as they are placed into the story (e.g. “It was getting colder” – AIBO executes the sadness behaviour). In the robot mode, the software captures the user’s choices and stores them into a memory file (unique for each user) using an activation-based selection algorithm based on the recency and repetition of events (Nuxoll et al., 2004, 2010). In every session, the server uses the memory file, based on the user ID, in order to utilise it and update it with new user choices (frequency, timestamps and location of each story element). From the user's perspective, the robot's memory is represented in GUI as a suggestion list – offering the user story elements which had been selected previously in the current location. The user can either select one of the suggested elements or ignore them and select something new. We implemented this memory feature in order to make the robot a more active participant in the game – in this case it can help the user to choose appropriate story elements based on the user's interaction history with the system.

Behaviour ID	Behaviour Name	Duration (sec)	Energy	Mood	Total energy	Total mood
0	Active	-	-1	-2	-	-
1	Bored	15-20	+1	10	+8-10	+60-100
2	Happy	11.1	-1	3	-5	+15
3	Excited	16.4	-2	4	-8	+32
4	Tired	13.6	+10	-1	+70	-7
5	Digging	8.6	-6	+2	-24	+8
6	Pointing down	3.2	0	+1	0	+2
7	Sad	3.3	-1	-2	-2	-4
8	Ending	4	0	0	0	0
9	Walking Fwd.	5.5	-4	+2	-12	+6
10	Walking Bwd	5.5	-4	+3	-12	+6
11	Rotation	19.6	-4	+1	-40	+10
12	Sitting down	12	+3	+1	+18	+6
13	Standing up	6.5	-1	-1	-3	-3
14	Barking	2	-1	+2	-1	+2
15	Ball tracking	20	-3	+3	-30	+30
16	Laying down	16	+4	0	+32	0

Table 11: List of robot behaviours and how they affect the robot's internal states (in 2-second interval)

Additionally, we developed a short term memory for the AIBO which allowed the robot to 'remember' the average petting pressure values and utilise them according to the value of the pressure. A detected slight petting decreased the average value while a heavy petting increased it. Moreover, the algorithm compared the current petting value with the average stored value and executed one of three different barking feedback behaviours accordingly e.g. a slight petting (slight compared to the average) causes specific attention seeking barking. Furthermore, the algorithm used the current calculated petting value to affect AIBO's internal states accordingly e.g. a slight petting will increase the boredom level.

6.4 Evaluation

In this section we describe the experiment setup along with the methods used to record and investigate participants' preference for the AIBO robot companion, interaction mode and their general experience with the proposed system. The study included a pilot study with 10 different participants in order to test and evaluate AIBOStory prior to the main, long term study involving 20 participants.

6.4.1 Participants

For the pilot study we recruited 5 pairs of participants mainly from the University aged between 21 and 34 (mean 27.5) while for the main, long term study we recruited 10 pairs of participants aged between 21 and 42 (mean 26.15) from different disciplines. We grouped the participants randomly and the pairings remained constant throughout the 10 sessions (the grouping is analysed in the next section). All of the participants where completely unfamiliar and unaware of the research and they were briefed about the research before the demo session.

6.4.2 Procedure and experiment setup

Pilot study

We performed a pilot study prior to the main study. We randomly selected 10 participants from the University and explained how the system works and demonstrated a simple communication test. Before the experiment participants completed a demographic form and they were given a short instructional printed manual for the system. The testing environment was exactly the same as in the main study along with the hardware and software setup. We allowed the participants to interact with each other using AIBOStory for approximately 12-13 minutes each pair and immediately after the interaction we provided them with a short questionnaire. The questionnaire included open ended questions for general feedback and comments for improvements along with ratings regarding their experience with the system, the interface, their interaction with the robot, the tablet computers and their intention for future use.

Figure 54: Participants interacting with the AIBOs and the tablet computers in robot mode

Main study

For the main study, since our main goal was to investigate differences between the two proposed modes, we grouped the participants equally for both modes in order to balance the transitional effect from one mode to another. Each pair participated in 10 sessions, each session on a different day to maximise the effect of the long-term interaction. The first of the two groups started the experiment with the no-AIBO mode and moved on to the AIBO mode experiment, each mode consisting of 5 sessions. The second group started the experiment with the AIBO mode and concluded with the no-AIBO mode. Each participant completed a consent and demographic form prior to the experiment and was given a small presentation of the system and how it works. In each session, participants sat comfortably on bean bags and in different rooms, each holding a tablet PC installed with AIBOStory and the necessary application for video communication (Figure 54). We chose to use bean bags in order to make the users feel more relaxed and furthermore to bring them closer to the floor level where AIBOs can operate and move safely without the risk of falling from a desk. Each session had a fixed duration of approximately 13 minutes. Participants were asked to complete a questionnaire after the 1st and 5th session of each mode. The questionnaires where the same for all sessions and interaction modes. At the end of the 10th session, participants were asked to complete a final short questionnaire regarding their experience with the AIBO robot. During the sessions a video camera recorded the participants' behaviour and facial expressions along with their interaction with the AIBO. Additionally, AIBOStory captured and saved participants' stories and choices as log files on the tablet computers, for later analysis.

6.4.3 Methods

The AIBOStory main study collected a large amount of participant's input using different measures, including several questionnaires, logged files from the server and GUI, video data, demographic forms and robot logged data. Our previous AIBOcom study (Papadopoulos, Dautenhahn, & Ho, in press) extensively analysed human-robot and human-human log files and data and successfully identified suitable methods for extracting and analysing significant information relevant to the study. Therefore, we utilised these methods to identify significant differences between the two proposed modes by comparing participants' preferences from the sessions in one mode with the sessions in the other. In order to analyse the overall user preference we summed up the values from sessions 1 and 5 from both modes and compared these values together using parametric tests since we treated the values as intervals (Norman, 2010). We treat the data as intervals because each question was accompanied by a visual analogue scale where the categories are equally spaced thus making the argument of treating the data as intervals even stronger. Furthermore, combining two Likert scales give us the advantage of having more scale values, which improves the reliability and the score distribution and enriches our concept of measuring the overall (from session 1 to session 5) preference between the two modes (Likert, 1932). Apart from comparing the two modes, we also used the questionnaire data to analyse human-robot experience during the interactions and the robot's behaviours. Additionally, we investigated participants' preferences for the robot's embedded memory/suggestions feature that AIBOStory offered by comparing the differences between the first and the last sessions. Furthermore, we used the logged data from the AIBOs and the AIBOStory system to analyse the usage of the suggestions feature and to count the number of human to robot pettings that occurred during the AIBO mode. As part of the logged data, we also analysed the lengths of the written stories. In addition, the author of this thesis also read all the stories and kept notes of the extent to which they made "sense". Disengagement of users from the game could create stories that did not make sense, i.e. stories where story elements might have been aligned randomly. The outcome for a "meaningful" story was derived from the right usage of elements (no unexplained repetitions) and a logical continuation of a story. Narrative in communication can engage and enhance the interaction between two distant users, if the story follows certain rules such as flow and logical sequence (order of events). Flow occurs when humans are highly involved with the activity of story writing and it offers an enjoyable experience (Csikszentmihalyi, 2000). Therefore, the person who experiences flow in his story will seek it again in the future, as he becomes self-motivated, and a story that makes sense and is created with a series of logical events is considered an enjoyable story that is easy to follow and understand, especially in AIBOStory, where two people construct a shared story.

6.5 Results

In this section, we present questionnaire results and logged data derived from the story writing which reflect the usability of the system and participants' preferences regarding

Human-Robot Interaction, story content and length. Additionally, we present the demographic data from the pilot and main studies such as their age, gender, experience in computer games and robots and finally their average video communication usage (Tables 12-13). Section 6.5.1 presents results from the pilot study regarding the overall preference and system acceptance. Sections 6.5.2-6.5.5 list results derived from our main long-term study along with the corresponding statistical analysis. The questionnaire results are based on Likert scales therefore values from 1 to 5 are used where 3 means neutral rating, 1 = negative and 5 positive.

	Age	Gender	Computer games (1-5)	Robots (1-5)	Video communication (Hours/week)
Participant 1	33	M	5	5	15
Participant 2	29	M	4	2	2
Participant 3	21	M	5	3	3
Participant 4	21	M	2	1	30
Participant 5	25	M	3	2	5
Participant 6	24	M	4	4	2
Participant 7	31	M	4	4	7
Participant 8	34	M	2	3	2
Participant 9	32	M	4	5	1
Participant 10	25	F	2	2	10

Table 12: Demographic data from the pilot study

	Age	Gender	Computer games (1-5)	Robots (1-5)	Video communication (Hours/week)
Participant 1	25	F	5	3	4
Participant 2	23	F	2	4	60
Participant 3	26	F	4	1	5
Participant 4	28	M	3	2	3
Participant 5	26	M	5	1	15
Participant 6	26	M	3	1	2
Participant 7	26	M	4	2	4
Participant 8	25	F	3	1	0
Participant 9	23	M	5	3	15
Participant 10	22	M	3	2	5
Participant 11	24	M	3	2	1
Participant 12	24	M	4	3	1
Participant 13	27	M	1	1	3
Participant 14	28	M	5	4	9

Participant 15	31	F	3	3	1
Participant 16	24	M	1	1	5
Participant 17	25	F	3	1	0
Participant 18	27	M	5	1	12
Participant 19	42	M	5	4	0
Participant 20	21	F	4	1	0

Table 13: Demographic data from the main study

Pilot study

6.5.1 Acceptance questionnaire results

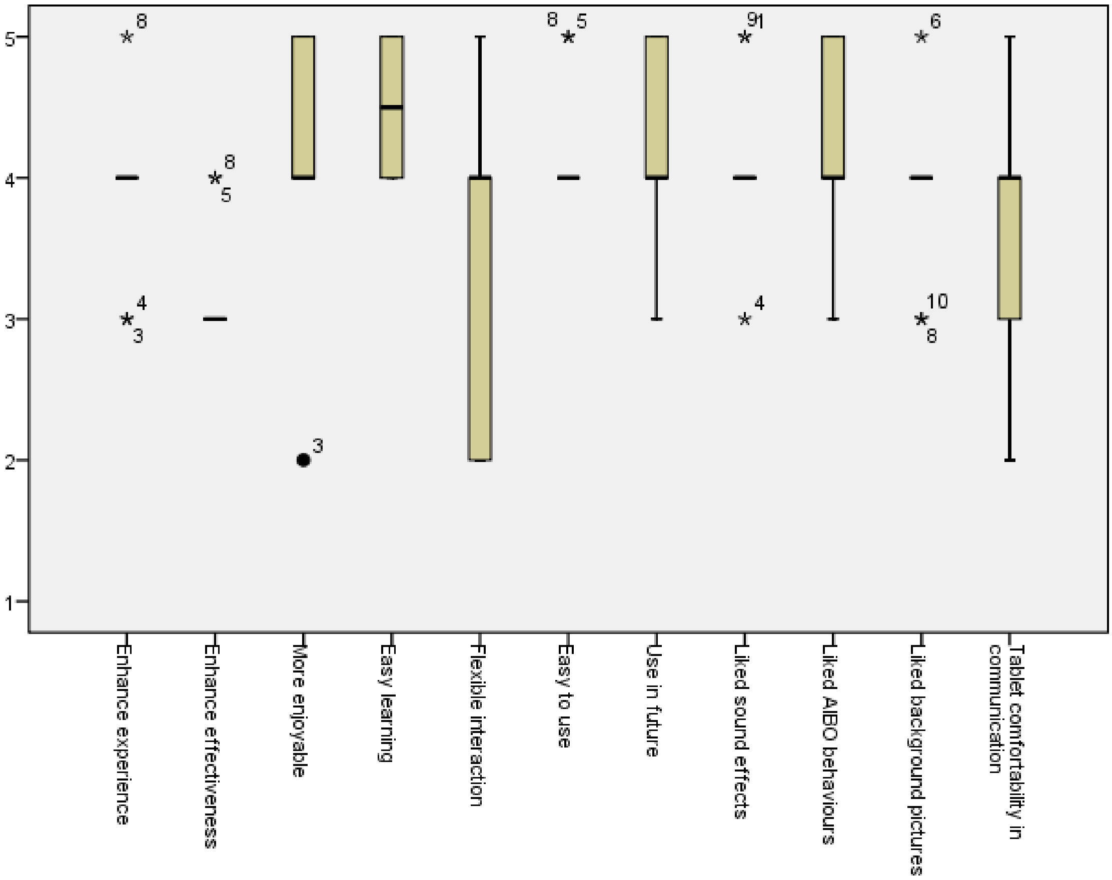


Figure 55: Pilot study results

Figure 55 shows the median results derived from the pilot study with the 10 participants. It shows that generally participants liked the system and its features. They also felt comfortable with the tablet computers and found the system easy to use and interact with. Additionally, the pilot study informed us about the system design and possible flaws that we addressed later. Participants’ comments revealed the necessity of bigger story element buttons and labels as well as the need of using various sound effects after each selected action. After the pilot study, we addressed these comments to improve usability and system performance.

Main study

6.5.2 General story telling statistics

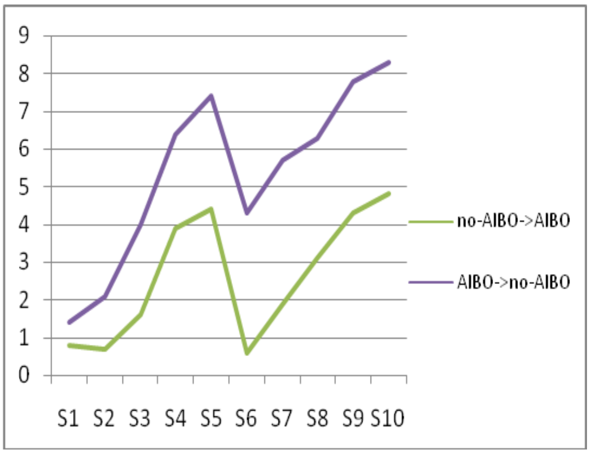


Figure 56: Custom story elements usage over the 10 sessions

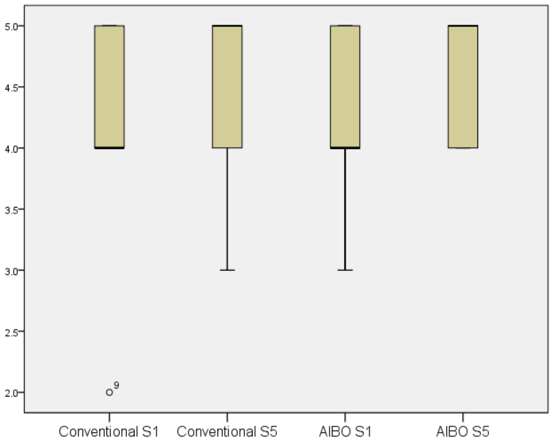
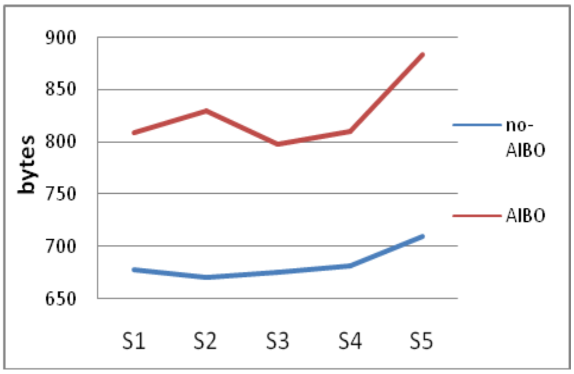


Figure 57: System difficulty on both modes

Figure 56 displays the correlation between the two participant groups from session 1 to session 10 in regards to the usage of custom story elements. The first group utilised the AIBO first and then moved to the no-AIBO mode from sessions 6 to 10. The second group started without the AIBO and then moved to the AIBO mode. The values on the vertical axis correspond to the number of times a custom story element was used. A statistically significant correlation was found using the Pearson’s correlation with a value of 0.918 and a significant value of 0.0001. Figure 57 shows the participants’ ratings regarding the difficulty of the system for both modes in sessions 1 and 5. Higher values indicate easier control and usage of the system. Statistical tests found no significant results between the two modes and sessions however, both ratings are above 4 on the Likert scale which indicates a system easy to use and learn.



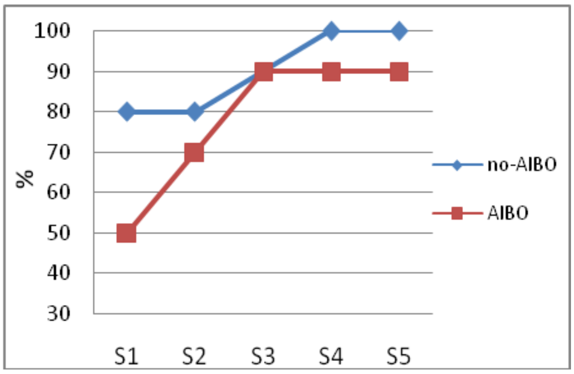
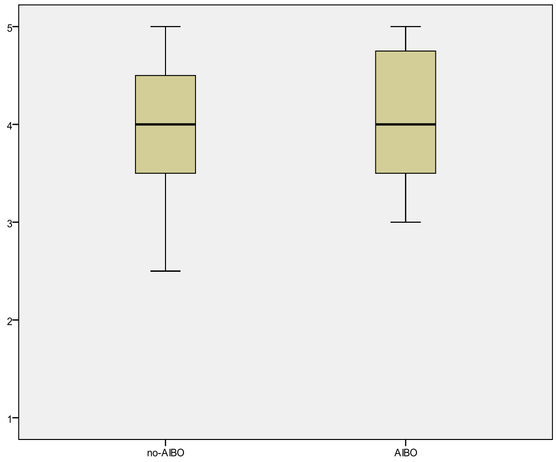


Figure 58: Story length in bytes

Figure 59: Story sense

Figure 58 represents the length of the written stories in bytes during the sessions on both modes. Generally, participants wrote longer stories in the AIBO mode than in the no-AIBO mode. Figure 59 shows the percentage of stories that made sense for both modes. A story makes sense when participants use related elements in a logical sequence and with a rational continuation in time

6.5.3 Interaction modes comparison



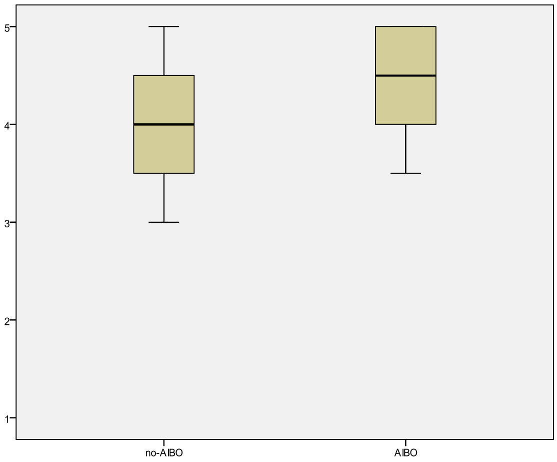


Figure 60: Communication and interaction experience between the

Figure 61: Overall communication experience

Figure 60 represents the median values for the communication and interaction preference between the two modes. A Cronbach's Alpha test value of 0.780 in favour of AIBO mode supports that participants preferred this mode over the no-AIBO mode however, an F-Test did not show any significant differences. Figure 61 shows the difference between the two modes for the participants' overall communication experience with clearly higher ratings for the AIBO mode than the no-AIBO mode. A statistical test supports this difference with a Cronbach's Alpha value of 0.860 and a significant value of 0.002 from an F-Test.

6.5.4 Human-Robot Interaction experience

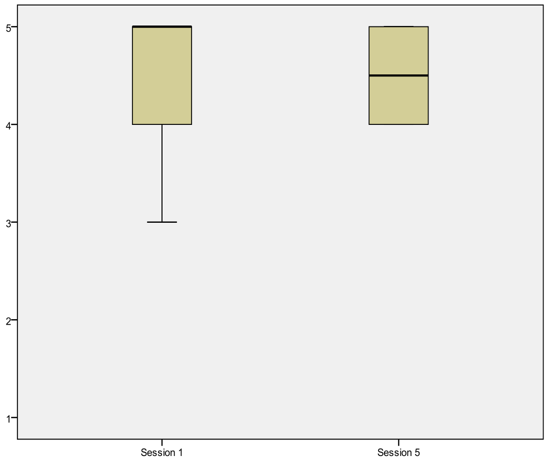


Figure 62: Robot's behavior experience

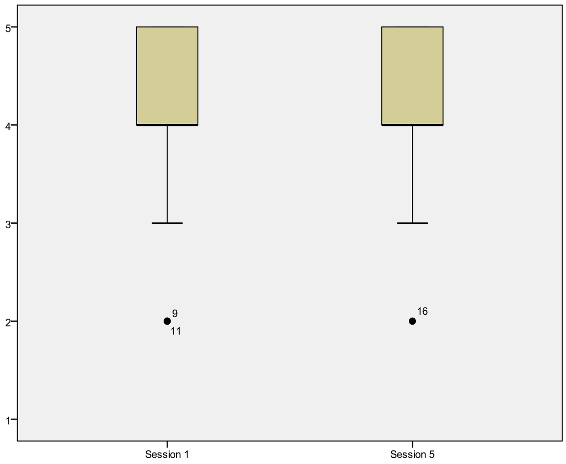


Figure 63: AIBO collaboration in the system

Figure 62 displays the participants' ratings with regards to their experience with the AIBO robots during sessions 1 and 5. Overall, the values are above 4 which indicate positive ratings. Similarly, Figure 63 shows the participants' judgement for AIBO collaboration in the system during session 1 and 5. Participants' scores remained unaffected between the sessions however, the ratings where positive.

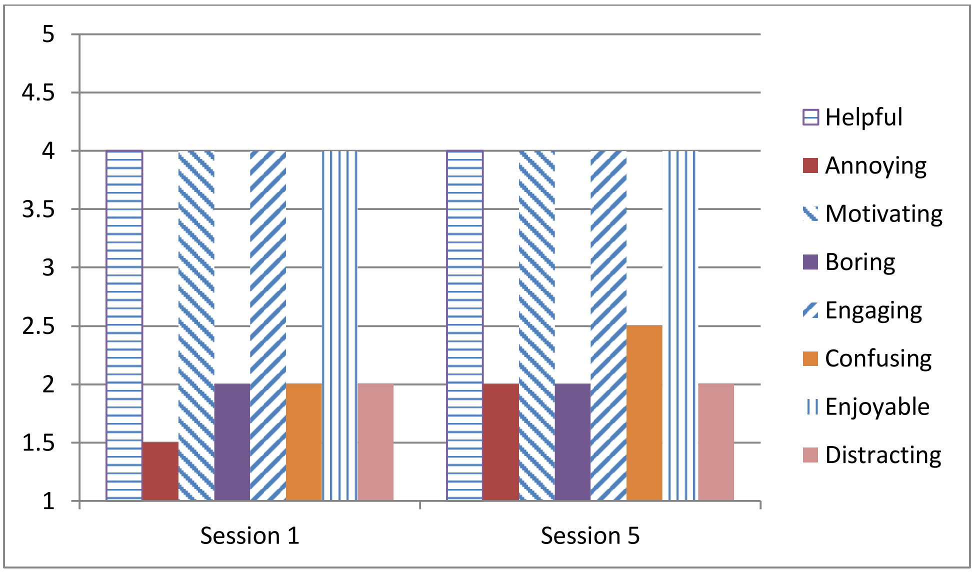


Figure 64: AIBO behaviours ratings

Figure 64 shows a number of bars that correspond to the participants' ratings for the various behaviours that the AIBO robot executed during the communication. Generally, participants enjoyed the AIBO behaviours and ranked them with an average value of 4 compared to the negative ratings which scored 2 overall. The difference between the negative and positive ratings is significant with the following values:

Helpful-Annoying: Session 1 (Z=-2.329, Sig.=0.02), Session 5 (Z=-2.584, Sig.=0.01)

Motivating-Boring: Session 1 (Z=-2.316, Sig.=0.021), Session 5 (Z=-2.913, Sig.=0.004)

Engaging-Confusing: Session 1 (Z=-2.205, Sig. =0.027), Session 5 (Z=-2.558, Sig. =0.011)

Enjoyable-Distracting: Session 1 (Z=-2.573, Sig. =0.01), Session 5 (Z=-2.327, Sig. =0.02)

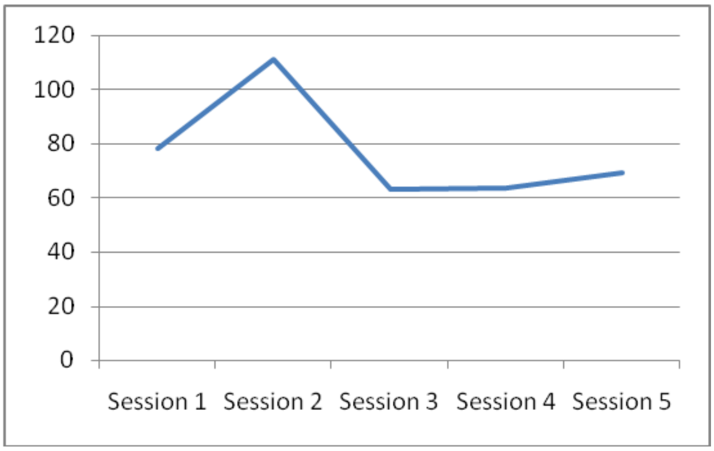
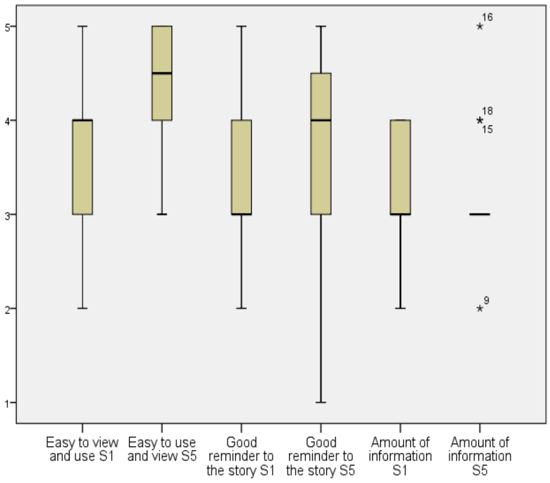


Figure 65: AIBO petting

Figure 65 shows values derived from participant's petting using the AIBO's tactile sensors during the 5 sessions. Generally, participants kept petting (interacting with) the AIBO with similar frequency over the sessions and a small fluctuation in the second session.

6.5.5 Memory statistics



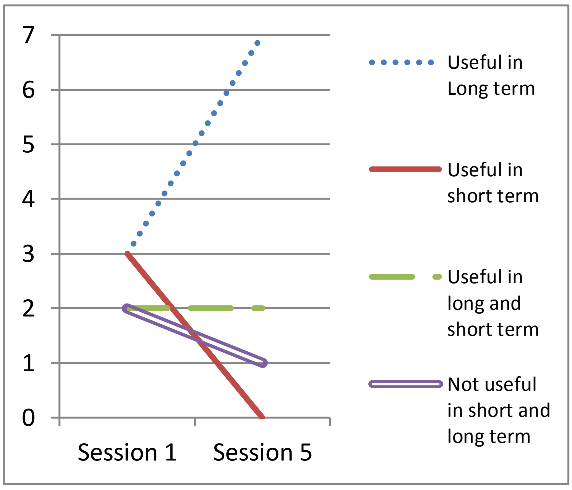


Figure 66: Suggestions feature

Figure 67: Suggestions feature usefulness

In Figure 66 sessions 1 and 5 display the 'suggestions feature/memory' ratings of the participants. The memory feature is an integral part of the AIBO's behaviour. The first bar shows how easy to view and use was the suggestion and presents a significant increase from session 1 to 5 (Wilcoxon Result Z=-2.36, Sig. =0.018). The second bar shows a slight increase from session 1 to 5 with no significant differences and the third bar remains the same throughout the sessions. Figure 67 represents the participants' ratings for the suggestion feature's usefulness throughout the sessions. 25% of the participants found the feature useful in long term communication in the first session while a significantly higher percentage of 55% was found on the 5th session (Wilcoxon Result Z=-2.236, Sig.=0.025).

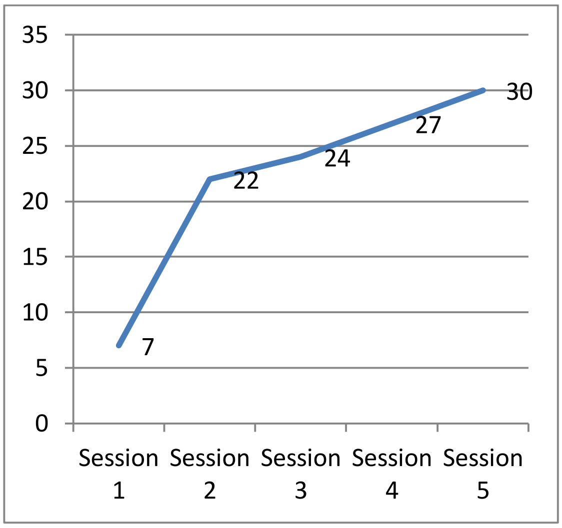


Figure 68: Suggestion usage over the 5 sessions

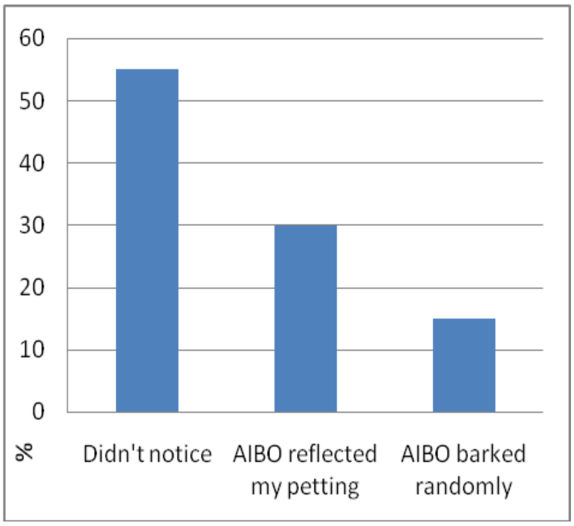


Figure 69: Different AIBO behaviours realization from the users

Figure 68 shows the number of times participants selected the suggested elements from the suggestion feature list during the communication for both participant groups. Generally, there is an increase over the sessions when both modes are combined. Lastly, Figure 69 shows the participants' score in percentages regarding their realisation of the different AIBO petting behaviours related to participant's touch pressure.

6.6 Discussion

Pilot study

6.6.1 Acceptance Questionnaire analysis

The pilot study included a questionnaire at the end of each session which was based on the UTAUT model. Overall, participants rated the system above the Neutral point for all questions apart for the effectiveness on the communication. We did not expect our system to improve the effectiveness of the communication since our goal was to make it more enjoyable to the participants by adding more features which subsequently increases the complexity of the system. As expected, participants found the system enjoyable, easy to use and learn, they were comfortable using the tablet computers, enjoyed the sound effects, AIBO's behaviours and the background pictures, and they found the system flexible during the interaction since they had the option to choose the robots for their communication. Moreover, participants agreed that they would use the system in the near future if it was available in the market at affordable price. They commented that the system offered an enjoyable interactive medium in the communication and the use of tablet computers was a good choice however, sometimes they complained about the touch screen control responsiveness and effectiveness during the communication.

Main study

6.6.2 General story statistics

Figure 56 shows the average values of custom story elements usage from the participants over the 5 sessions for both AIBO and no-AIBO modes. It is visible that both groups follow the same trend over the 5 sessions. The variation in average overall values between the two groups derives from the potential different cultural and educational background between the participants. A Pearson's correlation shows the significant relation among the groups as presented in Figure 56. The more they exploit and familiarise themselves with the system, the more they tend to choose alternative story elements. Consequently, when the participants change their interaction mode on the 6th session they lose their familiarity with the system and they focus more on exploring the new features rather than composing custom story elements. Figure 57 reflects the participants' ratings regarding the system difficulty on both modes. No significant difference was found between the two modes. The bars in Figure 57 show that participants found it easier to control the system on the last session for both modes as they progressively got more familiar with AIBOStory.

Figure 58 shows the length of the written stories, measured by using the size of each logged file in bytes. In the AIBO mode, participants were introduced with the AIBO robots which made them to share more information by utilising the story elements more frequently. Furthermore, since AIBO was executing most of the elements, participants were urged to explore the robot's behaviours by selecting and trying various elements. Participants' desire to explore robots' functionalities is supported from the results in Figure 59 where the written stories in AIBO mode in session 1 did not form a logical representation. However, as participants proceeded through the sessions and got more familiar with the robot, they started to use AIBOStory and the AIBO in a more communicative way which made the stories more meaningful. On the other hand, even though participants got familiar with the robots after the first two sessions, still the average number of stories in the no-AIBO mode was more meaningful than in the AIBO mode. This may have been caused by the robot's autonomous behaviours which were executed automatically as a result to affect the story, but they may have also distracted the participants from the tablet computers.

6.6.3 Interaction modes comparison

Figure 60 represents the median values for the communication and interaction preference between the two modes. The results indicate a small difference in the preference towards AIBO mode which is supported from a Cronbach's Alpha test with a value of 0.780; however, an F-Test did not show any significant differences. Similarly, Figure 61 shows the difference between the two modes for the participants' overall communication experience with clearly higher ratings for the AIBO mode than the no-AIBO mode. The 'overall communication experience' question relates to all the features that AIBOStory had, including the AIBO robots with their embedded suggestions feature in contrast with the 'communication and interaction preference' question. A statistical test supports this difference with a Cronbach's Alpha value of 0.860 and a significant value of 0.002 from an F-Test. We suggest that participants preferred the AIBO mode because the AIBO robots made the communication more enjoyable, as commented in the questionnaire's "open text" sections. Participants wrote 38 times that the AIBO was 'fun', 23 times that it was 'enjoyable', and 17 times that it was 'interesting'.

6.6.4 Human-Robot Interaction experience

Figure 62 shows the median values of participants' ratings regarding their experience with the robots for session 1 and 5. Participants rated the interaction with 4 which indicates they enjoyed the AIBO's behaviours during the communication. In the 5th session, participants rated the interaction higher than in the 1st session mainly because they learnt how to interpret and use the AIBO behaviours along with the AIBOStory. Similarly, participants positively rated the system for the AIBO collaboration with the game (Figure 63). From session 1 until session 5 the ratings remained unchanged with small insignificant fluctuations. The results above suggest a positive Human-Robot Interaction during the communication through the modes. Moreover, participants ranked the AIBO's behaviours positively throughout the sessions whilst ranking negatively the opposite questionnaire items. In the questionnaire, we gave participants two opposite categories (Figure 64) and let them choose a level of satisfaction or dissatisfaction. Results from the AIBO logged data regarding the participant petting also suggest that participant kept interacting with the robots during the sessions with a similar rate (Figure 65).

6.6.5 Memory suggestion feature analysis

The AIBO robots participated in the story-creation process via an integrated memory-based ‘suggestion feature’. This feature can help participants creating a story by offering a short list of previously chosen elements. The suggestions feature will present a list to the user which reminds the participant of his previous choices based on the current AIBOStory location. The suggestions feature thus reflects the user’s interaction history with AIBOStory. The user will either choose one of the items on the list or choose a new element that was not on the list. Figure 66 shows the participants' ratings regarding the suggestion feature which is grouped into 3 categories: Easy to view and use, Good reminder for story and Amount of information (quantity). Since the suggestion feature is based on the number of interactions, after every session the list gets longer. Comparing results for significant differences from the 1st session with the 5th session shows that participants found the feature quite easy and useful in the 1st session (mean 3.75) however, in the 5th session they rated it with a mean value of 4.5 which shows a significant increase (Sig.=0.018). Initially, participants found this feature complicated to use because of the small screen and resolution of the tablet computer which affected the visibility of the feature. Nevertheless, as participants proceeded through the sessions, they learned how to take advantage of the suggestions more easily and utilised this feature increasingly as seen in Figure 68. The questionnaire result is supported from the AIBOStory log files that captured the number of times of custom story elements’ usage as shown in Figure 56. Moreover, 25% of the participants found the suggestions feature useful for long term communication and interactions in the 1st session and significantly more participants (55%) found it useful in the 5th session (Figure 67). Finally, we also wanted to analyse the participants' realisation regarding the AIBO short term memory of petting and behaviour. At the end of the five AIBO mode sessions, participants were given a short questionnaire asking them if they recognised the different behaviours of the AIBO derived from each petting as shown in Figure 69. A small amount of participants recognised that the petting pressure affected the AIBO's behaviours however, 70% of the participants failed to recognise it. We believe that a vast amount of participants failed to recognise the different barking behaviours because during the communication they were focusing on the story construction and could not pay much attention to the AIBO.

Overall, based on the significant results taken from the questionnaire data as shown above regarding the interaction mode preference, participants overall preferred the AIBO mode in the long term use of the AIBOStory system. Furthermore, positive results from the logged data and the questionnaires regarding system adaptation to the user (i.e. AIBO memory and suggestion feature) suggest that in the long term communication participants found the suggestions feature increasingly useful over the sessions in their interactions. These findings highlight the importance of memory in long-term Human-Robot Interaction. Such features should thus be carefully considered and designed accordingly in future implementations.

The majority of the participants failed to identify the different robot barking behaviours based on individual user’s average pressures value. We believe that longer and more direct Human-Robot Interaction are essential for identifying personalised behaviours from the robots in the same way as humans communicate in a personalised manner as in our scenario participants did not focus solely on the robots. Finally, Human-Robot

Interaction logged data revealed that participants enjoyed their interactions with the robots and rated them positively in the questionnaires.

6.7 Conclusions

The main goal of this study was to compare two interaction modes during a remote human-human communication experiment between two users while they were developing a shared story through a computer device. The proposed system included a mode with a robot mediating communication and story construction (AIBO mode) and a mode without a robot (no-AIBO mode). In the robot mode users had to interact with the AIBOs in order to 'satisfy' the robots' internal states and at the same time, the robots physically expressed the content of the story with dog-like behaviours during the communication and story development. Moreover, in this particular mode, the exploratory AIBO suggestions feature was exposed to the users in order to facilitate them with the choice of subsequent story elements and allow us to explore the importance of basic robot memory on human-robot and human-human interactions. We performed a pilot study in order to evaluate the acceptance of our system and some general feedback was received for further improvements. After the pilot study, we conducted the main, long term study with 20 participants who used the system for 10 consecutive sessions. Two groups of participants exposed on both AIBO and no-AIBO modes in a counter-balanced experimental design. Participants completed various questionnaires in order to evaluate the Human-Robot Interaction and the features of the system and compare the two interaction modes. In general, participants preferred the AIBO mode over the no-AIBO mode and showed positive attitude towards robots' expressive behaviours (R3Q1 & R3R2). Additionally, although the memory-based 'suggestion feature' was not used and preferred as much as we had anticipated, results show an increasing usage rate over the sessions and we believe that users require time to familiarise themselves with such feature as the suggestion elements usage increased over the sessions (R3Q3). Furthermore, although in this study we did not utilise the video data to analyse human-robot and human-human interaction, we based our analysis on our previous methodologies from Chapter 4 and 5 where we identified various suitable techniques to extract these information from our data collection. Additionally, we adapted our methodologies in order to suit long-term interaction in multiple sessions. Therefore, this new methodology could be used on future studies where long-term remote human-robot and human-human interaction analysis is required and it could enhanced with the addition of video analysis as described in previous chapters (RQ3).

The results of this study signify the role of a robot and a memory element on remote communications for long-term interactions. However, we believe that users should interact for longer periods in the robot mode in order to get more familiar with the Human-Robot Interaction and the additional features that the robot adds to the communication channel.

6.8 Chapter Summary

AIBOStory is remote interactive story telling software that allows users to create and share common stories through an intergraded, autonomous robot companion acting as a social mediator. It works by nestling over the top of online chatting software and aims to enrich remote communication experiences over the Internet. A pilot study was conducted prior to the long-term experiment in order to evaluate the proposed system's use and acceptance by the users. Five pairs were exposed to the system, with the robot acting as a social mediator, and the results suggested an overall positive acceptance response. The system was later evaluated through a long-term study which involved 20 participants in order to compare their preferences between a robot that utilises a computational memory model and a non-robot mode. Instruments used in this study included multiple questionnaires from different communication sessions, demographic forms and logged data from the robots and the system. We used various techniques such as quantitative (e.g. rate of occurrence and median values) and qualitative measurements (e.g. story continuity/sense) to measure user preference and Human-Robot Interaction. Significant correlations were found, which suggest user predilection towards the robot mode, while the questionnaire and logged data indicate a fairly significant leaning towards interaction between the user and the robot. Furthermore, findings from our long-term study indicate that users utilised the memory feature increasingly more as the sessions progressed.

Chapter 7: Conclusions

7.1 Summary and Conclusions

The main goal of this PhD research was to examine and evaluate the importance of robots as social mediators in human-human remote communication. For that reason, we performed a series of experiments in order to study various aspects and limitations of such systems and answer our three main research questions set in Chapter 1. At the beginning of this PhD we performed an exploratory study with a suitable social mediator platform in order to identify various human-robot, human-human interactions and robot's operating modes. The first study utilised two robots -one on each remote end- acting as social mediator translating participant's intentions to navigate inside a virtual 2D maze. In this communication game we introduced two different interaction modes in order to identify the most preferable and enjoyable mode by the users. The affecting and mirroring modes controlled the synchronisation between the robots and the virtual games. The results from this exploratory study revealed that users preferred and enjoyed the mirroring mode than the affecting mode in this task-oriented game. The mirroring mode enhanced participants' awareness of presence as this specific mode simulated the sensation of collaboratively operating one robot instead of two distant ones to the participants. However, it should be noted that the interaction mode is highly dependable on the interaction and communication between the participants. Additionally, this study highlighted the importance of verbal communication between the participants during their interaction with the robots and the system. Participants usually find intelligent robots to be complicated devices that require familiarisation prior an interaction that involves complicated tasks. However, participants managed to overcome any difficulties with robot interaction and interface control with the help of substantial and constructive information they exchanged through the communication channel. Generally, the robot mode was enjoyable for the participants, with the mirroring mode being the most preferable for the current communication task as it was based on a collaborative game scenario.

Our first study explored various aspects of robot mediated human-human remote communication and formed the basis of a new platform for further investigating the mediator role in communication. In order to investigate the importance of robots in such communication, we developed a new platform based on our previous findings to compare two communication modes, one with a robot as social mediator and one without. Additionally, this new study explored the participants' behaviours and reactions with our system in regards to user enjoyment and satisfaction. This new platform was based on the mirroring mode as it proved to be more enjoyable for the users in collaborative scenarios. In this study we compared the two proposed modes and analysed the results from the questionnaires and video data and found that users overall enjoyed the robot over the no-Robot mode although it lacked of performance and efficiency. Furthermore, it became evident that the robot mode allowed the participants to exchange more social cues with each other, such as smiles or content with non-task oriented speech. However, we also found evidence that participants lacked of performance in the communication game when utilising the robots as mediator devices compared to conventional devices. This particular finding stresses the importance of selecting an appropriate medium of supportive interaction through a computer interface such as robots, joysticks, haptic devices etc. as task oriented scenarios require a lot of effort from users.

Our third study was based on our two former experiments which explored multiple aspects of robots in human-human remote communication. We identified that users preferred the mirroring mode for robot-robot synchronisation as this type of communication increased participants' awareness of presence and collaborative operation with the same robot. Additionally, our second experiment investigated the importance of selecting the appropriate interaction medium for the corresponding communication task. A task-oriented game proved to be difficult for the participants as they found it hard to effectively control the game with robots. For that reason, in our third experiment we introduced a non-task oriented type of communication between the users with robots acting as social mediators. The scenario was based on a shared story construction between the participants with robots acting as part of the story and executing various dog-like behaviours based on the chosen story elements. Similarly to the previous study, this experiment included two communication modes, one with the robot mediating the story and one without. A long-term study was conducted with 20 participants and results showed that users preferred the robot over the conventional mode. The non-task oriented nature of communication of this study displayed the importance of choosing an appropriate scenario for communications mediated by domestic robots. Additionally, participants expressed positive attitude towards the interactive dog-like behaviours that AIBO performed during the communication. Furthermore, the robot mode included an exploratory memory algorithm to help the users chose an appropriate story element based on their previous choices. Results regarding this feature showed an increasing usage over the sessions with users marking it as helpful and easy to use during the remote communication.

To summarise, our results from the three studies have answered our research questions and explored further aspects of human-robot and human-human interactions. The research questions that we set prior the studies were:

RQ1: *Can an autonomous robot be a social mediator in human-human remote communication?*

RQ2: *How does an autonomous robotic mediator compare to a conventional computer interface in facilitating users' remote communication?*

RQ3: *Which methodology should be used for qualitative and quantitative measurements for local user-robot and user-user social remote interactions?*

The first research question (RQ1) was answered from all of our three studies from multiple measurements such as feedback questionnaires, video analysis and Human-Robot Interaction logged data. We define a robot as social mediator a device that can increase and transfer social stimuli from one user to the other. In human-human communication various social stimuli could be transferred such as facial expressions, non-task conversation, collaborative touch, experience sharing and the sense of collaboratively working with the same robot. In our first study with the AIBOcom platform, participants rated our system above 4 in the Likert scale (1 to 5) for both modes, suggesting that they enjoyed the communication mediated by AIBO robots. Additionally, this study revealed the factors that contributed towards a successful collaboration between the distant users with the help of the social mediator. The mirroring mode in this game allowed the participants to feel like working with the same robot and as a result, collaboration was direct and easier. Also, the mirroring mode which controlled the synchronisation between the robots, affected participants' awareness of working with the same robot although they were located in different rooms. During the experiments, participants occasionally found the Human-Robot Interaction and game control rather difficult therefore, they utilised the communication channel to help each other and at the same time share their personal experiences with the robots. Likewise, our second study (AiBone) showed the same preference of the participant towards the robots in the communication. Additionally, this study analysed the exhibited social cues such as smiles and non-task conversation between the participants which were significantly higher in the robot mode compared to a conventional input control. This finding partially answers our second research question (RQ2). Our third study (AIBOStory), extended the analysis of participants' preference on long-term Human-Robot interaction and displayed a significantly higher rate of preference towards the robot mode in comparison to the conventional mode.

Our second research question (RQ2) focused on comparing a robotic social mediator on remote communication with ordinary conventional devices. The first study (AIBOcom) did not include any alternative controlling modes and therefore, in our second and third study we introduced the conventional mode, to allow participants to interact with each other by utilising both robots and conventional devices such as keyboard and mouse. Participants rated the robot mode high (above 4 in a 1-5 Likert scale) in questionnaires and generally enjoyed and preferred this mode compared to a conventional mode without robots. The direct comparison between a robot and a non-robot mode revealed that robots made the communication more enjoyable and allowed the participants to share more social cues with each other than the conventional mode. These findings answered our second research question (RQ2) and additionally explored the limitations of such system on task-oriented scenarios. Additionally, participants found the robots interesting and sometimes helpful in their communication.

Our final research question (RQ3) focused on exploring methods for analysing human-robot and human-human interactions in remote communication scenarios by utilising robots as social mediators. In our first study we performed an extensive video analysis on our data that revealed various methods for measuring qualitative and quantitative information, which helped us to evaluate the importance and usage of robots as social mediators. Furthermore, we extracted and analysed information from multiple questionnaires and log files that were used for identifying various human-robot and human-human interactions. These measurements have been successfully applied on all of our three studies objectively and explored robots' performances, behaviours, interactions with humans and most importantly human-human behavioural data.

Besides the three main research questions that this thesis delivers, our individual studies included several research questions that have been answered from our statistical analysis, video observation and coding and various data analysis.

Our first study included the following research questions:

R1M: *How should two interactive robots remotely influence each other's behaviour in order to enhance audio and video (AV) communications between two remote humans? Specifically, which of the two modes of robot-robot communication implemented ('mirroring' and 'affecting') are preferred by the participants?*

The majority of the participants rated the mirroring mode higher than the affecting mode and further video analysis showed that they preferred the mirroring mode more.

Further research questions from this study where:

R1Q1: *Are there any general meaningful links among the experiment results?*

The statistical results, data analysis and observational data provided interesting and useful information that could be used as guidelines for similar future studies and provided multiple significant results.

R1Q2: *Are participants influenced by remote users' behaviours and postures?*

Video communication between the distant participants helped them to exchange useful and constructive information in order to overcome difficulties with robot interaction and interface control. This communication highlights the significance of human-human cooperation and positive influence on their behaviours.

R1Q3: *Does the human-human and human-robot synchronisation have an effect on cooperative performance?*

Participants performed more efficiently when using the mirroring mode and the results have shown the importance of human-human and human-robot synchronisation and the significant positive effect on overall experience in the system.

Our second study addressed the following research question:

R2Q: *Which of the two modes (Conventional and Robot mode) is preferred by the participants in the context of playing a two-player computer game, and which participant experience is associated with these two game modes?*

Our second study was based on a competitive game scenario which involved virtual character manipulation through robots and conventional devices. The findings from this study suggest that users preferred the conventional mode for pure playing and efficient cooperation and manipulation however, further analysis showed that overall participants preferred the robot mode as it offered a better user-user and user-robot experience, more exhibited social cues between the participants and an enjoyable communication.

Finally, our third long-term study included the following research questions:

R3Q1: *Would users overall enjoy the AIBO robot in repeated communication over several sessions using AIBOStory?*

Our long-term study revealed that participants enjoyed the robot mediated communication over the sessions in comparison to a no-robot mode.

R3Q2: *Will the users enjoy the robot's behaviours integrated into the AIBOStory system compared to not using any robot?*

Participants preferred the robot mode over the no-robot mode and showed positive attitude towards robots' expressive behaviours.

R3Q3: *Will users utilise a memory feature in their communication that will remind them with their previous choices and sessions?*

Results showed an increasingly usage rate of the memory feature in the communication over the sessions although it was not used and preferred as initially anticipated.

7.2 Guidelines for developing Robots as social mediators

During this PhD research, we designed, developed and evaluated three different social mediator platforms for enhancing the remote communication between distant participants. During the process, we identified the importance of performing pilot studies prior to the main study to evaluate and update the social mediator platform according to users' needs and preferences. A pilot study can inform us about the real requirements of the participants for the user study as well as to make us aware of any imperfections that can cause user frustration during the interaction. Additionally, the pilot study will set the required measurements for analysing human-robot and human-human interactions involved in the experiment. These data can be analysed in order to provide us with an indication of the forthcoming main study results and to examine whether the proposed communication platform and system setup is adequate for answering our research questions in the specific study.

The most common human-human remote video communication utilises ordinary computers to transfer the audio and visual information to the users. For that reason, we can use the computer hardware to connect and synchronise two distant robots and at the same time offer an interactive platform for the users in order to enhance their current communication. For a reliable robot synchronisation the communication between the platforms and the robots should be simple and only the necessary information should be transmitted. Results from the three studies indicated that users still prefer to use conventional input devices for controlling and synchronising virtual movements through distance therefore, a non-competitive task should be offered through an interactive application. Our first and second studies involved a competitive computer game controlled with the help of AIBO robots which sometimes caused frustration to the users, although overall they preferred this interaction mode as it was more enjoyable. Our third study utilised a non-competitive task based on shared story creation where the participants could compose their own story with various story elements and AIBO robots served the role of physical story representation and interactive companion. We believe that the nature of the task should be non-competitive as it can provide a more comfortable environment to the users to interact with their robots and at the same time communicate with their distant partner. Additionally, the task should not be demanding from the users and should offer an enjoyable task that will maintain users' interest at high levels for longer periods of time.

As far as the robot is concerned, it should be able to operate in autonomous mode in order to avoid unnecessary Human-Robot interaction caused by the robot's inability to perform on its own capacity. The autonomous mode of the robot should satisfy some basic guidelines to allow the user to interact with the remote user and offer an enjoyable Human-Robot Interaction. A robot should not behave in an intrusive manner as this will distract the user from communicating with the remote user, which could cause frustration resulting from repetitive and unwanted behaviours. Additionally, the behavioural list of the robot should be long enough to offer a variety of actions without frequent repetition which would result in it becoming uninteresting to the users. The behaviours are highly dependable on the robot's embodiment as users tend to expect the robot to behave and react according to its physical appearance. In our scenarios where two AIBOs utilised as social mediators, we implemented dog-like behaviours with barking sounds derived from small sized dogs and reactions inspired from human to animal interactions. Since social mediators are usually small sized robots, their battery life is limited and therefore, special consideration should be given on behaviour implementation for maximum energy efficiency.

Interactions with intelligent robots should provide an immediate feedback to the users as normal animals do. Therefore, the robots should be equipped with personalised behavioural planning based on the users' preferences. Each user interacts with the robot differently and thus the robot should adapt to the unique user's preferences such as the petting pressure. Such personalisation will benefit the Human-Robot Interaction as the robot will understand the user's intention with a higher rate of success and it will provide them with the appropriate behaviour as a response. In our implementation, AIBO stored users' average petting pressure and used this information to recognise the type of the current petting. A similar approach could be used on other robotic embodiments as long as they are equipped with capacitive sensors.

The social mediator will run in autonomous mode therefore, an artificial mind should exist in order to impersonate an existing entity such as dogs. We developed the autonomous mode based on various internal states that drive the robot's personality and execution of behaviours. An autonomous mode should offer realistic behaviour execution in order to increase user believability and interest during the communication and Human-Robot Interaction. For long-term interactions robots should adapt their personality (internal states) to users' preference and attitude. An example of such adaptation is the internal state fluctuation from multiple Human-Robot Interaction. If a user is petting his robot with an average pressure and frequency and then suddenly performs a heavy petting then the robot will react accordingly and store this unusual information as a negative internal state influence.

To summarise, based on our studies, the list below suggests a few points for improving the development of robots as social mediators in remote communication scenarios:

- Use computer games (non-task oriented preferably) for enhancing user's experience and visualisation of the given scenario: User games enhance the interaction experience, but games that are too task-oriented impact negatively on the social and communicative aspects of the interaction.
- Choose robots with multiple behaviours based on their embodiment: A large behaviour repertoire allows more complex and varied scenarios
- Design autonomous robot behaviours to be consistent with robot's embodiment: i.e. adapt the robot's behaviour to its appearance, e.g. animal-like behaviour for a zoomorphic robot
- Design a system to be adaptive to human interactions: Adaptive systems allow for more engaging interactions in particular in long-term interactions

7.3 Contribution to knowledge

This research study is the first to systematically analyse the role of autonomous robots as social mediators in human-human remote communication. During this research we performed three different studies to investigate various aspects of human-robot and human-human interactions. We implemented an autonomous companion robot to operate and serve as social mediator in distant communication with the help of two personal computers. We have successfully identified a significant predilection towards robots in the role of social mediators and compared them to normal input devices such as keyboard and mouse. The first exploratory study revealed the most preferable and efficient synchronisation between the robots and the platforms (mirroring) which was later confirmed with the comparative and long-term studies. We thoroughly analysed this synchronisation mode and identified that people collaborate and communicate easier with this mode as it provides them the feeling of working together with the same robot.

Our final long-term study revealed users' preference on repetitive communication scenarios with robots as social mediators. We found that a robot could be utilised as social mediator in long-term scenarios as long as the platform offers customisable elements for a more personalised interaction and the robots offer a large variety of behaviours. Our questionnaire results before and after the study revealed the same preference and enjoyment rate towards robots during the communication. This finding from the long-term study revealed the importance of fully customisable graphical user interfaces and furthermore the competency of the robot to adapt to users' input.

In order to evaluate the information derived from such studies, we investigated various methodologies for video and questionnaire data analysis. We identified several methods for analysing human-robot and human-human interactions such as number of petting, gaze at robot, gaze at screen, verbal communication with task and non-task related information, number of smiles and more. These behaviours indicate the number of times a user interacted with the remote user or the robot and can classify the social cues exhibition during the communication.

Lastly, we developed our platform based on multiple components in order to make it modular and compatible with other software. The robot software is programmed in URBI language which allows the code to run in multiple robotic embodiments supported by URBI. The main communication application is divided into two parts: the linker and the interface. The linker is responsible for all the low level commands and connectivity between the computer and the robot and the interface displays the appropriate elements for human-human collaboration and play. Having the platform divided in three different modules, it allows a researcher to perform changes and alterations to specific modules without re-writing the complete communication system. Additionally, our first social mediator implementation has been successfully converted into the LIREC 3-layer architecture as discussed in Appendix V which shares various modules with other robotic embodiments allowing it to run in different operating systems. This architecture can be further expanded to allow our communication platform to operate different robotic embodiments such as the PLEO or the NAO robots since the hardware is being controlled from the low level modules.

Ultimately, we hope the findings from our studies will inform other researchers who aim to develop robots as social mediators, whether in a remote communication context, as addressed in this chapter, or in other contexts such as therapy, rehabilitation or remote collaboration, or other contexts and application areas where robots may benefit people on how they relate to each other and technological artefacts.

Generally, we have identified various features, implementation techniques and evaluation methods that could form a successful human-human remote communication platform with robots as social mediators.

7.4 Limitations

Our research interest did not focus on identifying every single aspect and characteristics of a robot based remote social mediation, but to research various achievable solutions and scenarios by performing a number of exploratory experiments. For that reason, during this PhD research we performed three different explorative studies with a total number of 80 participants, recorded their feedback and analysed their experiences with the robots and generally with our system. We investigated various issues and problems that users experienced with our system and tried to address most of them with new versions of software or by introducing completely new systems. However, there are some issues that we could not be addressed and limited our system usage during the studies. One issue that we discovered after the first study was the high latency values on the communication channel which affected the computer-computer and robot-robot synchronisation. The mirroring mode required a direct synchronisation in order to allow the users to realise their immediate participation in the system. However, we addressed this problem partially by adjusting the type of collaboration (combination of affecting and mirroring mode) and the frequency of synchronised movements.

Additionally, we found that the hardware of the AIBO was relatively old as the production of the latest version seized around 2006. Therefore, some modules were running in limited mode such as the camera resolution and overall the speed of the actuators. The camera had a very low resolution which affected the ball tracking algorithm by occasionally giving false readings thus miscalculating fast ball movements. The slow actuators affected the behaviour execution as well and limited the degree of natural dog-like behaviours. The only solution to this problem is to replace the AIBO robots with newer robots such as the NAO models.

Besides the hardware limitations of our platform, we also identified some software and controlling issues that limited the functionality of our system. In our last experiment we implemented a memory feature to help the users decide which story elements to choose in an easier and faster manner. Although the memory feature had an increasing rate of usage over the sessions, we recognise that a more advanced and complicated implementation of such feature could have offered a better experience to the users and achieved a more efficient utilisation. Lastly, we identified the level of difficulty that participants had during their concurrently interaction with computer and robot during their communication in order to collaborate and successfully finish the given task. We partially addressed this issue by introducing a non-competitive task to the users however, the autonomous nature of the robot interrupted the human-computer interaction during the communication thus limiting their efficiency in the task.

7.5 Future work

In the previous section we identified various factors that affected the usability of our system for the proposed communication while in this section we will list our future plans for further improvements. Participants' feedback and questionnaire analysis revealed that users generally enjoyed the various dog-like behaviours however, they found them limited in terms of duration and number of unique actions. Furthermore, the autonomous level of the robots affected participants’ attitude towards the robots and facilitated them to express more social cues between them. For that reason, we believe that a richer repertoire of embedded dog-like behaviours and impulsive AIBO actions would enhance participants’ perception of interacting with an autonomous intelligent robot thus encouraging them to share their personal experiences even more. Every new version of our platform included new behaviours, but we suggest to develop more dog-like behaviours in order to further increase robot's believability.

Our third study included a non-competitive task which proved to be more preferable to the users than the competitive tasks that our first two studies offered. Although the computer interface of our third study included various components and visual effects, some participants found them rather limited after the five first sessions of continuous interactions. Participants expressed their preference towards the changes of environmental cues for different locations, highlighting the importance of different scenery. We believe that a dynamically operated user interface would enhance users’ perception and believability of the selected scenery positively. In the future version we suggest to use dynamic backgrounds that will change depending on time and weather conditions of the written story. Additionally, more customisable sound effects may increase users' interest and enjoyment during the story development and sharing.

Apart from interface enhancements, we extracted useful information regarding participants’ perception towards memory utilisation that our third implementation offered. The current exploratory implementation did not stimulate the participants to effectively utilise the proposed memory architecture and they did not pay adequate attention to the personalised petting adaptation that AIBO robot offered. Although this memory feature was adequate for the current story sharing interface, we believe that a more sophisticated memory algorithm will benefit the users in long-term interactions with the robots and the remote users. Furthermore, the memory implementation could be enhanced with additional features such as remembering interaction patterns (for story element selection) and offer the recorded information more descriptive and interactively. Additionally, the embedded AIBO petting adaptation feature could be modified to offer more informative feedback to the participants in order for them to realise its functionality. For an improved next implementation we suggest to use a memory algorithm to allow the robot remember various user preferences such as the preferable distance between the user and the robot, adaptable threshold levels for behaviour activation, the volume of barking, the most preferable behaviours along with customised speed and more Human-Robot Interaction patterns that could be recorded and used for future interactions.

Lastly, we would suggest to use more robots in our system such as the NAO or PLEO. We have integrated the LIREC 3-layer architecture in our first experiment platform which allowed it to use any robot capable of running the URBI server (see Appendix V). The robot modules that we developed for our first study can be used for the second and third experiment platforms (AiBone and AIBOStory) as well. Both NAO and PLEO robots support URBI commands therefore, in order to utilise them with our systems, we need to use the same URBI file from the AIBO robot to the new robots and change some commands and configuration file.

We believe that a communication system based on AIBOStory but with a better graphical user interface, a more sophisticated memory algorithm, a richer repertoire of behaviours and the choice to use alternative robots will further enhance our approach towards the development of an enjoyable and successful communication platform for long-term interactions that can further enhance and maintain human-human remote communication.

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Appendix I: Demographic and questionnaire forms

This chapter will list the questionnaire and demographic forms used for AIBOcom, AiBone and AIBOStory user studies. Before each user study session, participants where first given the appropriate consent and demographic forms. The first questionnaire form was given to 20 participants after they completed interacting with the AIBOcom platform in both synchronisation modes (affecting and mirroring). The AiBone questionnaire forms were given to 40 participants after they interacted with both conventional and robot modes. The AIBOStory study included two different questionnaire forms that were given to the 20 participants in several sessions. Questionnaire Q1 was given after the first and fifth sessions in the robot mode while questionnaire Q2 was generic and was used after the first and fifth sessions in the non-robot mode and as a supplementary form to Q1 in the robot mode.

AIBOcom study

AIBOcom Questionnaire

ID Number: ☐ ☐☐

---

1) How do you judge the cooperation between ***you and the robot***:

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral

☐ Unsatisfactory

☐ Very unsatisfactory

If you were not satisfied, could you explain why?..

....

2) How pet-like did the robot react to your directions:

☐ Very pet-like

☐ Quite pet-like

☐ Neutral

☐ Not pet-like

☐ Not pet-like at all

If it was not or not at all pet-like, could you explain why?..

....

3) How intelligently did the robot react to your interaction?

☐ Very intelligently

☐ Quite intelligently

☐ Neutral

☐ Unintelligently

☐ Very unintelligently

If it did react unintelligently, could you explain why?...

....

4) How did you experience the cooperation between ***you and the other user (mode 1)***:

☐ Very satisfactory

☐ Quite satisfactory

☐ Neutral

☐ Quite unsatisfactory

☐ Very unsatisfactory

If it was unsatisfactory could you explain why? ....

....

5) How did you experience the cooperation between ***you and the other user (mode 2)***:

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral
☐ Quite unsatisfactory
☐ Very unsatisfactory

If it was unsatisfactory could you explain why?................................

....

6) How fast or slowly did you learn to control and interact with the AIBO?

☐ Very fast
☐ Quite fast
☐ Neutral
☐ Slowly
☐ Very slowly

7) How easy or difficult was it to control the virtual character using the AIBO?

☐ Very easy
☐ Quite easy
☐ Neutral
☐ Difficult
☐ Very Difficult

If it was difficult or very difficult could you explain why?................................

....

8) Did you finish the maze (mode 1 or mode 2)? **Mode 1 / Mode 2**

If not, could you explain why?..

……………………………………………………………………………….

9) How did you experience the first multiplayer mode (mode 1 – same virtual character)?

☐ Enjoyed very much

☐ Enjoyed a little bit

☐ Neutral

☐ Did not enjoy

☐ Did not enjoy at all

Would you like to explain your decision?...

....

10) How did you experience the second multiplayer mode (mode 2 – individual virtual character)?

☐ Enjoyed very much

☐ Enjoyed a little bit

☐ Neutral

☐ Did not enjoy

☐ Did not enjoy at all

Would you like to explain your decision?...

....

11) In your opinion, how important is the use of voice or body gesture to co-ordinate your activities in the maze with the other user?

Voice

1 2 3 4 5

Not important at all Very important

Body

1 2 3 4 5

Not important at all Very important

12) If you wanted to play any multiplayer games in the future, would you use this interaction technology?

1 2 3 4 5

Definitely not Definitely yes

Would you like to explain your decision?...
....

13) If you wanted to communicate and interact with another person remotely, compared to e.g. other video communication software such as Skype, would you use this interaction technology in the future as a game?

1 2 3 4 5

Definitely not Definitely yes

Would you like to explain your decision?...
....

AIBOcom: Robot enhanced video communication

Section 1: Information about the AIBOcom and Lirec project

LIREC is a collaboration of 10 European partners specialized in psychology, ethology, human-computer interaction, human-robot interaction, robotics and graphical characters.

The LIREC network aims to create a new generation of interactive, emotionally intelligent companions that is capable of long-term relationships with humans.

The research team focuses on both virtual companions and physical embodiments such as robots. They also examine how people react to a familiar companion when it migrates from a robot body into a virtual form, for example on a mobile PDA screen.

AIBOcom is an interactive game as a part of Lirec project that aims to enhance the current remote video communications by introducing a robotic companion in the communication. At the current stage AIBOcom uses AIBO as a social mediator to reproduce and transfer haptic interaction to both users.

The research will involve some questionnaires and collection of video material required for the analysis of the experiments. All data collected on individual participants will be treated with full confidentiality. At no time throughout the whole course of the research project will your name or any other personal details that you provide be identifiable, (i.e. your name will not appear in any internal or external publications). All evaluation work will be based on the participant numbers allocated to each subject. This ID code will form the basis of our evaluations, not your real name.

Participation in this study is entirely voluntary. If at any point you do not wish to continue with the study, you may withdraw, this will not reflect badly on you. The questionnaires provided do not have any right or wrong answers, nor should they be viewed as tests. However, you can decide not to answer certain questions in the questionnaires provided if you do not wish to.

Section 2: Consent to take part in the trials

Name of Researchers: Prof. Kerstin Dautenhahn, Fotios Papadopoulos, Dr. Steve Ho

(PLEASE INITIAL BOXES)

I CONFIRM THAT I HAVE READ AND FULLY UNDERSTOOD THE INFORMATION PROVIDED FOR THE ABOVE STUDY. I UNDERSTAND THAT MY PARTICIPATION IS VOLUNTARY AND THAT I AM FREE TO WITHDRAW AT ANY TIME, WITHOUT GIVING ANY REASON. I AGREE TO TAKE PART IN THE ABOVE STUDY. ☐

WE WOULD LIKE TO USE SOME OF THE VIDEO FOOTAGE FOR FUTURE CONFERENCES AND PUBLICATIONS. I CONSENT TO MY VIDEO FOOTAGE RECORDED DURING THE EXPERIMENTS TO BE USED FOR THIS PURPOSE. ☐

ID NUMBER ☐☐☐

Name of participant: ______________________________

Signature: ____

Date: ____

If you have any questions regarding the above study, please contact the experimenter, Fotios Papadopoulos f.papadopoulos1@herts.ac.uk

Thank you.

Section 3: About You

Before we get started with the trials, we would be grateful if you could complete the questions below:

1. Gender: Male ☐ Female ☐
2. Age: ☐☐
3. Occupation or course if you are a student: ……………………………………………………
4. Relationship with the remote user:…………………………………………………………….
5. Handedness: left-handed ☐ right-handed ☐ either ☐
6. Please state your level of familiarity with the following:

    a) Entertainment Robots (e.g. robots seen in films, portrayed in literature)

Very unfamiliar	Quite unfamiliar	3 Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you view or read about ***entertainment robots***

____

b) Toy Robots (e.g. Aibo, Furby, Pleo)

Very unfamiliar	Quite unfamiliar	3 Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you spend interacting with ***toy robots***

____

c) If you are familiar with robots, is this related to:

1) Occupation ☐
2) Hobby/Leisure ☐
3) Both ☐
4) Not Applicable ☐

7. Do you use any video communication software (e.g. Skype. MSN, etc)?

Yes ☐ No ☐

If **yes**, please state approximately, on average how many hours a week you spend using computer applications such as communication software and which one.

____

8. If money was of no concern, and you could afford to buy a robot for your home, would you be interested in buying one?

Yes ☐ No ☐

AiBone study

AIBOcom v2 Questionnaire

ID Number: ☐☐☐

When options are provided, please tick only one box for each of the questions 1-12 below.

1) How do you judge the interaction with the robot?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Did not enjoy at all

2) How do you judge the cooperation between ***you and the robot***:

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral
☐ Unsatisfactory
☐ Very unsatisfactory

If you were not satisfied, could you explain why?...

....

3) How intelligently did the robot react to your interaction?

☐ Very intelligently
☐ Quite intelligently
☐ Neutral
☐ Unintelligently
☐ Very unintelligently

If it did react unintelligently, could you explain why?..

....

4) How did you experience the cooperation and coordination between ***you and the other user (conventional mode, mouse + keyboard)***:

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral
☐ Quite unsatisfactory
☐ Very unsatisfactory

If it was unsatisfactory could you explain why? ....

....

5) How did you experience the cooperation and coordination between ***you and the other user (AIBO robot mode)***:

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral
☐ Quite unsatisfactory
☐ Very unsatisfactory

If it was unsatisfactory could you explain why?................................

....

6) How fast or slow did you learn to control and interact with the AIBO?

- ☐ Very fast
- ☐ Quite fast
- ☐ Neutral
- ☐ Slowly
- ☐ Very slowly

7) How easy or difficult was it to control the virtual character using the AIBO?

- ☐ Very easy
- ☐ Quite easy
- ☐ Neutral
- ☐ Difficult
- ☐ Very Difficult

If it was difficult or very difficult could you explain why?................................

....

8) How easy or difficult was it to control the virtual character using keyboard and mouse?

- ☐ Very easy
- ☐ Quite easy
- ☐ Neutral
- ☐ Difficult
- ☐ Very Difficult

If it was difficult or very difficult could you explain why?................................

....

9) How did you experience the conventional multiplayer mode (***mouse + keyboard***)?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Did not enjoy at all

Would you like to explain your decision?...

....

10) How did you experience the robotic multiplayer mode (***AIBO robot***)?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Did not enjoy at all

Would you like to explain your decision?...

....

11) How did you experience the robot’s sniffing behaviours?

☐ Helped me a lot
☐ Helped me a little bit
☐ Neutral
☐ Did not help me
☐ Did not help me at all

Would you like to explain your decision?...

....

12) How do you judge the tactile interaction with the AIBO?

- ☐ Very important
- ☐ Important
- ☐ Neutral
- ☐ Not very important
- ☐ Not important at all

13) In your opinion, how important is the use of voice or body gesture to co-ordinate your activities in the game with the other user?

Conventional Mode:

Voice

1 2 3 4 5

Not important at all Very important

Body

1 2 3 4 5

Not important at all Very important

AIBO Mode:

Voice

1 2 3 4 5

Not important at all Very important

Body

1 2 3 4 5

Not important at all Very important

14) If you wanted to play any multiplayer games in the future, would you use personal robots as an interaction technology?

|—1—2—3—4—5—|

Definitely not Definitely yes

Would you like to explain your decision?...

....

15) If you wanted to communicate and interact with another person remotely, e.g. using a video communication software such as Skype, would you use robots as an interaction method to play a game?

|—1—2—3—4—5—|

Definitely not Definitely yes

Would you like to explain your decision?...

....

AiBone: Robot enhanced video communication comparison study

Section 1: Information about the AIBOcom v2 and Lirec project

LIREC is a collaboration of 10 European partners specialized in psychology, ethology, human-computer interaction, human-robot interaction, robotics and graphical characters.
The LIREC network aims to create a new generation of interactive, emotionally intelligent companions that is capable of long-term relationships with humans.
The research team focuses on both virtual companions and physical embodiments such as robots. They also examine how people react to a familiar companion when it migrates from a robot body into a virtual form, for example on a mobile PDA screen.
AIBOcom v2 is an interactive game as a part of Lirec project that aims to extend the current remote video communications by introducing a robotic companion in the communication. At the current stage AIBOcom v2 uses AIBO robots as a social mediators to reproduce and transfer tactile interaction to both users along with a conventional mode where users utilize their keyboards and mice to play the game.

The research will involve some questionnaires and collection of video material required for the analysis of the experiments. All data collected on individual participants will be treated with full confidentiality. At no time throughout the whole course of the research project will your name or any other personal details that you provide be identifiable, (i.e. your name will not appear in any internal or external publications). All evaluation work will be based on the participant numbers allocated to each subject. This ID code will form the basis of our evaluations, not your real name.

Participation in this study is entirely voluntary. If at any point you do not wish to continue with the study, you may withdraw, this will not reflect badly on you. The questionnaires provided do not have any right or wrong answers, nor should they be viewed as tests. However, you can decide not to answer certain questions in the questionnaires provided if you do not wish to.

Section 2: Consent to take part in the trials

Name of Researchers: Prof. Kerstin Dautenhahn, Fotios Papadopoulos, Dr. Steve Ho

(PLEASE INITIAL BOXES)

I CONFIRM THAT I HAVE READ AND FULLY UNDERSTOOD THE INFORMATION PROVIDED FOR THE ABOVE STUDY. I UNDERSTAND THAT MY PARTICIPATION IS VOLUNTARY AND THAT I AM FREE TO WITHDRAW AT ☐

ANY TIME, WITHOUT GIVING ANY REASON. I AGREE TO TAKE PART IN THE ABOVE STUDY.

WE WOULD LIKE TO USE SOME OF THE VIDEO FOOTAGE FOR FUTURE CONFERENCES AND PUBLICATIONS. I CONSENT TO MY VIDEO FOOTAGE RECORDED DURING THE EXPERIMENTS TO BE USED FOR THIS PURPOSE. ☐

ID NUMBER ☐☐☐

Name of participant: ____________________

Signature: ____________________

Date: ____________________

If you have any questions regarding the above study, please contact the experimenter, Fotios Papadopoulos f.papadopoulos1@herts.ac.uk

Thank you.

Section 3: About You

Before we get started with the trials, we would be grateful if you could complete the questions below:

1. Age: ☐☐

2. Occupation or course if you are a student: …………………………………………………

3. Relationship with the remote user:……………………………………………………….

4. Handedness: left-handed ☐ right-handed ☐ either ☐

5. Please state your level of familiarity with the following:

a) Toy Robots (e.g. Aibo, Furby, Pleo)

1	2	3	4	5
Very unfamiliar	Quite unfamiliar	Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you spend interacting with ***toy robots***

____

b) Multiplayer computer games (any games and platforms)

1	2	3	4	5
Very unfamiliar	Quite unfamiliar	Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you play **multiplayer games**:

____

c) Games with feedback controllers (e.g. xbox vibration controller)

1	2	3	4	5
Very unfamiliar	Quite unfamiliar	Neutral	Quite familiar	Very familiar

6. Do you use any video communication software (e.g. Skype. MSN, etc)?

   Yes ☐ No ☐

   If **yes**, please state approximately, on average how many hours a week you spend using computer applications such as communication software and which one.

   ____

7. If money was of no concern, and you could afford to buy a robot for your home, would you be interested in buying one for the purpose of video communication?

   Yes ☐ No ☐

8. May we contact you to participate in similar studies in the future? If so, please provide contact information (email address or phone number):...
   ....

AIBOStory study

Questionnaire Q1

ID Number: ☐☐☐

Please tick only one of the above

1) How did you experience overall the robot's behaviours?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Did not enjoy at all

2) How well did the AIBO work as part of the game?

☐ Very well
☐ Well
☐ Neutral
☐ Not well
☐ Not well at all

3) The behaviours initiated by the AIBO were....

	Totally disagree	Disagree	Neutral	Agree	Totally agree
Helpful					
Annoying					
Motivating					
Boring					
Engaging					
Confusing					
Enjoyable					
Distracting					

4) Suggestions made by AIBO based on your previous choices...

	Totally disagree	Disagree	Neutral	Agree	Totally agree
...were easy to view and use					

...serve as a good reminder to write a story					
	Too much	Much	Just right	Little	Too little
...contain an amount of information that is					

5) How did you overall experience the “Suggestions” feature in the game?

- ☐ Enjoyed very much
- ☐ Enjoyed a little bit
- ☐ Neutral
- ☐ Did not enjoy
- ☐ Did not enjoy at all

6) How useful is the Suggestions feature?

- ☐ Useful in long-term and repeated interactions
- ☐ Useful in short-term interactions
- ☐ Useful in both long-term and short term interactions
- ☐ It is neither useful in short nor long-term interactions

7) How important do you think the Suggestions feature is...

	Not important at all	Not important	Neutral	Important	Very important
...for user-user remote communication?					
...for creating					

enjoyable stories?					
...for making the interaction between you and the other user easier?					
...for making the interaction between you and the robot less distracting?					

Questionnaire Q2

ID Number: ☐☐☐

When options are provided, please tick only one box for each of the questions 1-7 below.

1) How did you experience the interaction and communication between ***you and the other user***

☐ Very satisfactory
☐ Quite satisfactory
☐ Neutral
☐ Quite unsatisfactory
☐ Very unsatisfactory

Please explain why ....

....

2) How fast or slow did you learn to control and interact with the system?

☐ Very fast
☐ Quite fast

☐ Neutral
☐ Slowly
☐ Very slowly

3) How easy or difficult was the interface to you?

☐ Very easy
☐ Quite easy
☐ Neutral
☐ Difficult
☐ Very Difficult

Please explain why..

....

4) How did you experience the sound effects of the system including the background noise?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Din not enjoy at all

Please explain why...

....

5) How did you experience the background images?

☐ Enjoyed very much
☐ Enjoyed a little bit
☐ Neutral
☐ Did not enjoy
☐ Did not enjoy at all

Please explain why..

....

6) How did you experience the overall communication?

- ☐ Enjoyed very much
- ☐ Enjoyed a little bit
- ☐ Neutral
- ☐ Did not enjoy
- ☐ Did not enjoy at all

Please explain why..

....

7) If you wanted to communicate and interact with another person remotely for an enjoyable communication, e.g. using a video communication software such as Skype, would you use this tool as an interaction method to enhance your communication?

1 2 3 4 5

Definitely not Definitely yes

Please explain why..

....

AIBOStory: Robot enhanced video communication study with memory

Section 1: Information about the AIBOStory and Lirec project

LIREC is a collaboration of 10 European partners specialized in psychology, ethology, human-computer interaction, human-robot interaction, robotics and graphical characters.

The LIREC network aims to create a new generation of interactive, emotionally intelligent companions that is capable of long-term relationships with humans.
The research team focuses on both virtual companions and physical embodiments such as robots. They also examine how people react to a familiar companion when it migrates from a robot body into a virtual form, for example on a mobile PDA screen.
AIBOStory is an interactive platform as a part of Lirec project that aims to extend the current remote video communications by introducing a robotic companion in the communication. At the current stage AIBOStory uses AIBO robots as social mediators to reproduce and transfer tactile interaction to both users along with a conventional mode where users utilize their keyboards and mice to play the game and write their own story.

The research will involve some questionnaires and collection of video material required for the analysis of the experiments. All data collected on individual participants will be treated with full confidentiality. At no time throughout the whole course of the research project will your name or any other personal details that you provide be identifiable, (i.e. your name will not appear in any internal or external publications). All evaluation work will be based on the participant numbers allocated to each subject. This ID code will form the basis of our evaluations, not your real name.

Participation in this study is entirely voluntary. If at any point you do not wish to continue with the study, you may withdraw, this will not reflect badly on you. The questionnaires provided do not have any right or wrong answers, nor should they be viewed as tests. However, you can decide not to answer certain questions in the questionnaires provided if you do not wish to.

Section 2: Consent to take part in the trials

Name of Researchers: Prof. Kerstin Dautenhahn, Fotios Papadopoulos, Dr. Steve Ho

(PLEASE INITIAL BOXES)

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WE WOULD LIKE TO USE SOME OF THE VIDEO FOOTAGE FOR FUTURE CONFERENCES AND PUBLICATIONS. I CONSENT TO MY VIDEO FOOTAGE RECORDED DURING THE EXPERIMENTS TO BE USED FOR THIS PURPOSE. ☐

ID NUMBER ☐☐☐

Name of participant: ____

Signature: ____

Date: ____

If you have any questions regarding the above study, please contact the experimenter, Fotios Papadopoulos f.papadopoulos1@herts.ac.uk

Thank you.

Section 3: About You

Before we get started with the trials, we would be grateful if you could complete the questions below:

1. Age: ☐☐
2. Occupation or course if you are a student: ……………………………………………………
3. Relationship with the remote user:……………………………………………………………….
4. Handedness: left-handed ☐ right-handed ☐ either ☐

5. Please state your level of familiarity with the following:

a. Toy Robots (e.g. Aibo, Furby, Pleo)

		3		
Very unfamiliar	Quite unfamiliar	Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you spend interacting with ***toy robots***

____

b) Multiplayer computer games (any games and platforms)

1	2	3	4	5
Very unfamiliar	Quite unfamiliar	Neutral	Quite familiar	Very familiar

Please state approximately, on average how many hours a week you play **multiplayer games**:

6. Do you use any video communication software (e.g. Skype. MSN, etc)?

Yes ☐ No ☐

If **yes**, please state approximately, on average how many hours a week you spend using computer applications such as communication software and which one.

____

7. If money was of no concern, and you could afford to buy a robot for your home, would you be interested in buying one for the purpose of video communication?

Yes ☐ No ☐

8. May we contact you to participate in similar studies in the future? If so, please provide contact information (email address or phone number):...
....
....

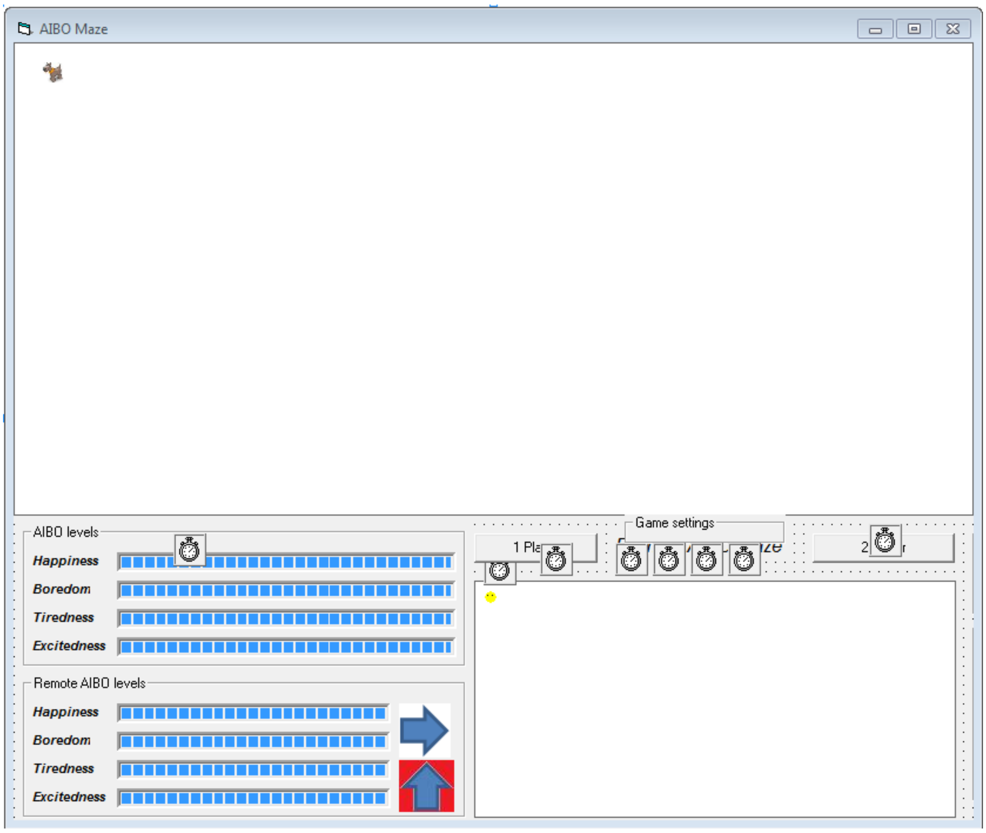
Personality Questionnaire

The following questions are taken from the TIPI – the Ten Item Personality Inventory. They are intended to measure your personality. It is included because, we are interested in how different types of people view and interact with robots. There are no right or wrong answers to this, and there is not one 'right' personality type for our studies. Also, we will not divulge your responses to these questions to members outside of our research team.

Trait	**Disagree strongly**	**Disagree moderately**	**Disagree a little**	**Neither agree nor disagree**	**Agree a little**	**Agree moderately**	**Agree strongly**
Extraverted, enthusiastic							
Critical, quarrelsome							
Dependable, self-disciplined							
Anxious, easily upset							
Open to new experiences, complex							
Reserved, quiet							
Sympathetic, warm							
Disorganised, careless							
Calm, emotionally stable							
Conventional, uncreative							

Appendix II: AIBOcom GUI, linker and AIBO Robot modules

AIBOcom interface



AIBOcom interface consists of the Project1.vbp, Form1.frm and Module1.bas files. The interface was developed using Microsoft Visual Basic 6 and the files are located under Experiment1\Interface folder.

AIBOcom linker

The linker consists of dll.dev (project file), dll.h and dll.cpp file and was written in C.

Dll.h:

```
#ifndef _DLL_H_
#define _DLL_H_
#if BUILDING_DLL
# define DLLIMPORT __declspec
(dllexport)
#else /* Not BUILDING_DLL */
# define DLLIMPORT __declspec
(dllimport)
#endif /* Not BUILDING_DLL */
class DLLIMPORT DllClass
{
  public:
    DllClass();
    virtual ~DllClass(void);
  private:
};
extern "C" __declspec( dllexport )
__stdcall int init(void);
extern "C" __declspec( dllexport )
__stdcall int gettir(void);
extern "C" __declspec( dllexport )
__stdcall int getbor(void);
extern "C" __declspec( dllexport )
__stdcall int getfri(void);
extern "C" __declspec( dllexport )
__stdcall int gethap(void);
extern "C" __declspec( dllexport )
__stdcall void shut(void);
extern "C" __declspec( dllexport )
__stdcall int fotis(void);
extern "C" __declspec( dllexport )
__stdcall int curaction(void);
extern "C" __declspec( dllexport )
__stdcall int setf(int a1,int a2,int
a3,int a4);
#endif /* _DLL_H_ */
```

Dll.cpp:

```
#include "dll.h"
#include <windows.h>
#include "urbi\UClient.hh"
#include "urbi\uabstractclient.hh"
#include "stdio.h"
#include "urbi\ucallbacks.hh"
#include "string"
#include <time.h>
#include <iostream>
#include <sstream>
//#include <stdio.h>
using namespace urbi;
using namespace std;
float tirCur=0;
float tirCur2=0;
int drives=0;
int fotios=0;
int curAct=0;
void sleep(unsigned int mseconds)
{
    clock_t goal = mseconds + clock();
    while (goal > clock());
}
UCallbackAction on1(const
UMessage &msg) {
        UValue ff=
*(UValue*)msg.value;
        tirCur=(float)ff.val;
        return URBI_CONTINUE;
}
UCallbackAction on2(const
UMessage &msg) {
        UValue ff=
*(UValue*)msg.value;
        tirCur2=(float)ff.val;
        return URBI_CONTINUE;
}
UCallbackAction on3(const
UMessage &msg) {
        UValue ff=
*(UValue*)msg.value;
        drives=(int)ff.val;
        return URBI_CONTINUE;
}
UCallbackAction on4(const
UMessage &msg) {
        UValue ff=
*(UValue*)msg.value;
        curAct=(int)ff.val;
        return URBI_CONTINUE;
}
/*
DllClass::DllClass()
{}
DllClass::~DllClass ()
{}
*/
UClient * cl= new
UClient("192.168.1.200");
extern "C" __declspec( dllexport )
__stdcall int init(void)
{
cl->setCallback(&on1, "headtilt");
cl->setCallback(&on2, "headpan");
cl->setCallback(&on3, "tired");
cl->setCallback(&on3, "bored");
cl->setCallback(&on3, "friendly");
cl->setCallback(&on3, "happy");
cl->setCallback(&on4, "curaction");
return 1;
}
extern "C" __declspec( dllexport )
__stdcall void shut(void)
{
    cl->send("robot.game=0;");
}
extern "C" __declspec( dllexport )
__stdcall int gettir(void)
{
    cl->send("tired << robot.tir;");
    Sleep(80);
    return drives;
}
extern "C" __declspec( dllexport )
__stdcall int getbor(void)
{
    cl->send("bored << robot.bor;");
    Sleep(80);
    return drives;
}
extern "C" __declspec( dllexport )
__stdcall int getfri(void)
{
    cl->send("friendly <<
robot.fri;");
    Sleep(80);
    return drives;
}
extern "C" __declspec( dllexport )
__stdcall int gethap(void)
{
    cl->send("happy << robot.exc;");
    Sleep(80);
    return drives;
}
extern "C" __declspec( dllexport )
__stdcall int curaction(void)
{
    int tmpcur=0;
    cl->send("curaction <<
robot.ActionF;");
    sleep(80);
    tmpcur=curAct;
    curAct=0;
    return tmpcur;
}
extern "C" __declspec( dllexport )
__stdcall int setf(int a1,int a2,int
a3,int a4)
{
std::stringstream s;
s << a1;
std::string str1 = s.str();
s.str("");
s << a2;
std::string str2 = s.str();
s.str("");
s << a3;
std::string str3 = s.str();
s.str("");
s << a4;
std::string str4 = s.str();
s.str("");
   cl->send("robot.fri=");
   sleep(50);
   cl->send(str1.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   cl->send("robot.bor=");
   sleep(50);
   cl->send(str2.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   cl->send("robot.tir=");
   sleep(50);
   cl->send(str3.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   cl->send("robot.exc=");
   sleep(50);
   cl->send(str4.c_str());
   sleep(50);
   cl->send(";");
   return 0;
}
extern "C" __declspec( dllexport )
__stdcall int fotis(void)
{
 int direction=0;
   if (cl->error()) urbi::exit(1);
   cl->send("headtilt <<
headTilt.val;");
   Sleep(50);
   cl->send("headpan <<
headPan.val;");
   Sleep(50);
   //up-down
   if((tirCur>18) &&
(tirCur<=28))direction=10;
   if(tirCur>28)direction=11;
   if((tirCur<2) && (tirCur>=-
8))direction=30;
   if(tirCur<-8)direction=31;
   //right-left
   if((tirCur2<-13) && (tirCur2>=-
33))
       if(direction!=0)
            direction=direction+45;
//55,56,75,76
       else
            direction=40;
   if(tirCur2<-33)
       if(direction!=0)

direction=direction+48;//58,59,78,79
       else
            direction=41;
   if((tirCur2>13) &&
(tirCur2<=33))
       if(direction!=0)

direction=direction+16;//26,27,46,47
       else
            direction=20;
   if(tirCur2>33)
       if(direction!=0)

direction=direction+32;//42,43,62,63
       else
            direction=21;
   if((tirCur<=13) && (tirCur>=2)
&& (tirCur2<=13) && (tirCur2>=-
13))direction=0;
   //urbi::execute();
   return direction;
}
BOOL APIENTRY DllMain
(HINSTANCE hInst     /* Library
instance handle. */ ,
                    DWORD reason
/* Reason this function is being
called. */ ,
                    LPVOID reserved     /*
Not used. */ )
{
   switch (reason)
```

```
  {
    case DLL_PROCESS_ATTACH:
      break;
    case DLL_PROCESS_DETACH:
      break;
    case DLL_THREAD_ATTACH:
      break;
    case DLL_THREAD_DETACH:
      break;
  }
    /* Returns TRUE on success,
FALSE on failure */
    return TRUE;
}
```

The linker files are located under Experiment1\Linker folder.

Robot file

```
//General
var robot.onfood=0;
var robot.choice=0;
var robot.migrate=0;
var robot.game=0;
var robot.sleeping=0;
var robot.behlegs=0;
var robot.behspeaker=0;
var robot.behears=0;
var robot.behcamera=0;
var robot.behtail=0;
var robot.behlights=0;
var robot.ex=0;
var robot.tir=0;
var robot.bor=0;
var robot.fri=0;
var robot.exc=0;
var robot.ActionF=10;
var robot.lastB=0;
var robot.borvar=0;
var robot.excLimit=30;
var robot.tirLimit=60;
var robot.borLimit=40;
var robot.friLimit=30;
var robot.gameend=0;
var robot.touchtemp=0;
var robot.touchaveg=0;
var robot.touchaveg0=0;
var robot.counttemp=0;
var robot.countaveg=0;
motors on;
wait(500);
robot.initial();
var ball.a = 0.9;
var lastvalPan=0;
var lastvalTilt=0;
whenever (robot.migrate==0){
//sleeps
if(robot.sleeping==0){
robot.LayDown();
headPan.val=0 smooth:1500ms &
neck.val=-78 smooth:1500ms;
modeR.val=1;
modeB.val=0;
modeG.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
robot.tir=0;
robot.bor=0;
robot.fri=0;
robot.exc=0;
robot.ActionF=10;
robot.lastB=0;
robot.borvar=0;
robot.excLimit=30;
robot.tirLimit=60;
robot.borLimit=40;
robot.friLimit=30;
robot.touchtemp=0;
robot.touchaveg=0;
robot.touchaveg0=0;
robot.counttemp=0;
robot.countaveg=0;
speaker.play("client.wav");
};
robot.sleeping=1;
robot.game=0;
}
else
//wakes up
{
if(robot.sleeping==1){
neck.val=0 smooth:1500ms;
modeR.val=0;
modeB.val=0;
modeG.val=1;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
robot.tir=0;
robot.bor=0;
robot.fri=0;
robot.exc=0;
robot.ActionF=10;
robot.lastB=0;
robot.borvar=0;
robot.excLimit=30;
robot.tirLimit=60;
robot.borLimit=40;
robot.friLimit=30;
robot.touchtemp=0;
robot.touchaveg=0;
robot.touchaveg0=0;
robot.counttemp=0;
robot.countaveg=0;
};
robot.sleeping=0;
};
// Main Game behavior
whenever (ball.visible ~ 100ms)
if(robot.game==1) {
lastvalPan=headPan.val;
lastvalTilt=headTilt.val;
headPan.val  = headPan.val + ball.a *
camera.xfov * ball.x &
if(headTilt.val<40){
headTilt.val = headTilt.val + ball.a *
camera.yfov * ball.y;}
else
{
headTilt.val = headTilt.val + ball.a *
camera.yfov * ball.y;
neck.val=neck.val +ball.a *
camera.yfov * ball.y;
};

};

at (!ball.visible ~ 100ms)
if(robot.game==1)search: {


                if(lastvalPan<headPan.val
)
                                {

                headPan.val   = 60
smooth:700ms;

                headPan.val   = 0
smooth:1200ms;
                                }
                                &

                if(lastvalTilt<headTilt.val
)
                                {

                headTilt.val=37
smooth:700ms;

                headTilt.val=14
smooth:1200ms;
                                }
                                else
                                {

                if(lastvalPan>headPan.val
)
                                {

                headPan.val=-60
smooth:700ms;

                headPan.val=0
smooth:1200ms;
                                }
                                &

                if(lastvalTilt>headTilt.val
)
                                {
```

```
            headTilt.val=-10
smooth:700ms;

            headTilt.val=14
smooth:1200ms;
            };
                        };
      };
at (!ball.visible ~ 2500ms)
if(robot.game==1){
headPan.val=0 smooth:1s &
headTilt.val=16 smooth:1s;
};

at (ball.visible) stop search;


modeG.val=1;
modeB.val=0;
modeR.val=0;

ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;


at((headSensor.val>7) &&
(robot.game==1))
{
tempcatch << every(10ms){
            whenever(headSensor.val
>7){

            robot.counttemp=robot.co
unttemp+1;

            robot.touchtemp=robot.to
uchtemp+headSensor.val;
            };};

ledF12.val=1 & ledF13.val=1 &
ledF11.val=0;

headPan.val=headPan.val+10
smooth:233ms &
headTilt.val=headTilt.val+6
smooth:233ms &
neck.val=neck.val+10
smooth:233ms;

headPan.val=headPan.val-3
smooth:233ms &
headTilt.val=headTilt.val-1
smooth:233ms;
neck.val=neck.val-6 smooth:233ms;

ledF12.val=0 & ledF13.val=0 &
ledF11.val=0;
}
onleave
{
stop tempcatch;
robot.touchtemp=robot.touchtemp/ro
bot.counttemp;

robot.countaveg=robot.countaveg+1;
robot.touchaveg0=robot.touchaveg0+
robot.touchtemp;
robot.touchaveg=robot.touchaveg0/r
obot.countaveg;

robot.touchtemp;
robot.touchaveg;

if(robot.touchtemp>robot.touchaveg-
4 &&
robot.touchtemp<robot.touchaveg+4)
{
if(speaker.playing!=1)speaker.play("
happy.wav");
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+8;
if(robot.tir>0)robot.tir=robot.tir-2;
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+4;
if(robot.bor>0)robot.bor=robot.bor-2;

}
else
if(robot.touchtemp>=robot.touchave
g+4)
{
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+5;
if(robot.tir>0)robot.tir=robot.tir-2;
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+2;
//if(robot.bor<robot.borLimit)robot.b
or=robot.bor+1;
if(speaker.playing!=1)speaker.play("
angry.wav");
}
else
{
if(speaker.playing!=1)speaker.play("
att.wav");
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+2;
if(robot.tir>0)robot.tir=robot.tir-1;
//robot.fri=robot.fri+2;
if(robot.bor<robot.borLimit)robot.bo
r+2;
};
robot.counttemp=0;
robot.touchtemp=0;

};

at((chinSensor.val>=1)&&
(robot.game==1))
{
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+15;
if(robot.bor<robot.borLimit)robot.bo
r=robot.bor-3;
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir-2;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};
at((backSensorF.val>25)&&
(robot.game==1))
{
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at((backSensorM.val>25)&&
(robot.game==1))
{
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at((backSensorR.val>25)&&
(robot.game==1))
{
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at((backSensorM.val>5 &&
backSensorM.val<=25)&&
(robot.game==1))
{
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;

};

at((backSensorF.val>5 &&
backSensorF.val<=25)&&
(robot.game==1))
{
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at((backSensorR.val>5 &&
backSensorR.val<=25)&&
(robot.game==1))
{
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};
```

```
at((headSensor.val>25)&&
(robot.game==1))

{
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+8;
if(robot.bor>0)robot.bor=robot.bor-1;
if(speaker.playing!=1)speaker.play("
angry.wav");
};


at((robot.tir>=-100) && (robot.tir<=-
10) && (robot.game==1) &&
(robot.gameend==0))
{
robot.tir=0;
robot.ActionF=7;
robot.game=0;
robot.end();
robot.migrate=0;
};

every(1500ms){

if(((robot.fri>=robot.friLimit) &&
(robot.borvar==0) &&
(robot.game==1))){
        if (robot.ActionF==10) {

        robot.ActionF=2;
        //      robot.friend();
        };
};

if(((robot.exc>=robot.excLimit) &&
(robot.borvar==0) &&
(robot.game==1))){
        if (robot.ActionF==10) {

        robot.ActionF=3;
        //      robot.excite();
        };
};

if(((robot.bor>=robot.borLimit) &&
(robot.borvar==0) &&
(robot.game==1))){
        if (robot.ActionF==10) {

        robot.ActionF=4;
        //      robot.bored();
        };
};

if(((robot.tir>=robot.tirLimit) &&
(robot.borvar==0) &&
(robot.game==1))){
        if (robot.ActionF==10) {

        robot.ActionF=5;
        //      robot.tired();
        };
};

if(robot.ActionF==3) //excited
{
        if(robot.exc>14)robot.exc
=robot.exc-3;
        if(robot.bor>8)robot.bor=
robot.bor-4;
        if(robot.tir<40)robot.tir=r
obot.tir+1;
//
        if(robot.fri<robot.friLimit
)robot.fri=robot.fri+1;
}
else if(robot.ActionF==4) //bored
{
        if(robot.exc>3)robot.exc=
robot.exc-1;
        if(robot.bor>3)robot.bor=
robot.bor-3;
        if(robot.tir>5)robot.tir=ro
bot.tir-1;
        if(robot.fri>5)robot.fri=ro
bot.fri-1;
}
else if(robot.ActionF==5)  //tired
{
        if(robot.exc>3)robot.exc=
robot.exc-1;
        //if(robot.bor>5)robot.bor
=robot.bor-1;
        if(robot.tir>7)robot.tir=ro
bot.tir-7;
        //if(robot.fri<25)robot.fri=
robot.fri+1;
}
else if(robot.ActionF==2)  //happy
{
        if(robot.exc<robot.excLi
mit)robot.exc=robot.exc+1;
        //if(robot.bor>5)robot.bor
=robot.bor-1;
        if(robot.tir>4)robot.tir=ro
bot.tir-4;
        if(robot.fri>3)robot.fri=ro
bot.fri-3;
}
else
{
if(((robot.exc>0) &&
(ball.visible==1) &&
(robot.game==1)))
robot.exc=robot.exc-1;
if(((robot.bor<robot.borLimit)&&(ba
ll.visible==0) &&
(robot.game==1)))robot.bor=robot.b
or+3;
//if(((robot.bor<robot.borLimit)&&(b
all.visible==1) &&
(robot.game==1)))robot.bor=robot.b
or-1;
if(((robot.tir<robot.tirLimit)&&(ball.
visible==1) &&
(robot.game==1)))robot.tir=robot.tir
+2;
if(((robot.tir>5)&&(ball.visible==0)
&&
(robot.game==1)))robot.tir=robot.tir-
3;
if(((robot.fri>0) && (ball.visible==0)
&& (robot.game==1)))
robot.fri=robot.fri-1;
};

};

function robot.excite()
{
if ((robot.ex==0) &&
(robot.migrate==1))
{
        robot.ex=1;
        //beg and happy
        if(robot.lastB==4){
        if(robot.behlegs==1)
                {

        legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28           time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &

        legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2            time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &

        legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
                };
        }
else
if(robot.behlegs==1) {
robot.StandUp();
}; if(robot.behlights==1){
modeG.val=1;
modeR.val=0;
modeB.val=0;

ledF1.val=1;
ledF2.val=1;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
};
if(robot.behlegs==1) {
legRF1.val=85 smooth:1500ms &
legRF2.val=0 smooth:1500ms &
legRF3.val=44 smooth:1500ms &

legRH1.val=-56 smooth:1s &
legRH2.val=0 smooth:1s &
legRH3.val=75 smooth:1s &

legLF1.val=85 smooth:1500ms &
legLF2.val=0 smooth:1500ms &
legLF3.val=44 smooth:1500ms &

legLH1.val=-56 smooth:1s &
legLH2.val=0 smooth:1s &
legLH3.val=75 smooth:1s &
};
 if((speaker.playing!=1) &&
(robot.behspeaker==1))speaker.play(
"exc1.wav") &
 if(robot.behcamera==1) {
if(ball.visible==0) headTilt.val=44
smooth:1s &
if(ball.visible==0) headPan.val=30
smooth:1s &
neck.val=2 smooth:1s;
};
if(robot.behtail==1){tailTilt.val=40
time:500ms &
tailmov << tailPan.val=-40 sin:3s
ampli:100},
if(robot.behcamera==1){
```

```
		headTilt.val=21
time:333ms &
if(ball.visible==0)headPan.val=-40
time:1s & };
if(robot.behspeaker==1){
mouth.val=-35 time:333ms;}; &
if((speaker.playing!=1) &&
(robot.behspeaker==1))speaker.play(
"exc1.wav");
if(robot.behspeaker==1){
mouth.val=-6 time:244ms;
};

if(robot.behlegs==1) {
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms &
}; if(robot.behcamera==1){
if(ball.visible==0)headPan.val=40
time:866ms}; &
if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if((speaker.playing!=1) &&
(robot.behspeaker==1))speaker.play(
"exc2.wav") }; &
 if(robot.behlegs==1) {
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;};

if(robot.behspeaker==1){mouth.val=
-6 time:144ms &};
 if(robot.behlegs==1) {
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=0 time:150ms &
legLF2.val=0 &
legRH2.val=0 time:150ms &
legRF2.val=0 &
};
if(robot.behcamera==1) {
if(ball.visible==0)headPan.val=0
time:666ms &
if(ball.visible==0)headTilt.val=44
time:1s & neck.val=2 time:1s;
}; if(robot.behspeaker==1){
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
exc2.wav");
mouth.val=-6 time:244ms;};
if(robot.behears==1){earL.val=1 &
earR.val=1}; &
if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
exc2.wav");};
if(robot.behears==1){earL.val=0 &
earR.val=0}; &
if(robot.behspeaker==1){mouth.val=
-6 time:244ms;};
if(robot.behlegs==1) {
legRF1.val=57 time:3s &
legRF2.val=0 time:2s &
legRF3.val=43 time:3s &
legRH1.val=-134 time:4s &
legRH2.val=1 time:1s &
legRH3.val=119 time:2s &
legLF1.val=57 time:3s &
legLF2.val=0 time:2s &
legLF3.val=43 time:3s &
legLH1.val=-134 time:4s &
legLH2.val=1 time:1s &
legLH3.val=119 time:2s & };
if(robot.behears==1){earL.val=0 &
earR.val=0 & };
if(robot.behcamera==1){neck.val=0
time:500ms & };
if(robot.behears==1){earL.val=1 &
earR.val=1 & };
if((ball.visible==0) &&
(robot.behcamera==1))headTilt.val=-
5 time:1s & if((ball.visible==0) &&
(robot.behcamera==1)){headPan.val
=0 time:1s & neck.val=2 time:1s}; &
if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)
speaker.play("exc1.wav");};
if(robot.behspeaker==1){mouth.val=
-6 time:244ms;};
//stopall;

robot.lastB=1;
stop tailmov;
robot.ActionF=10;
robot.ex=0;
//robot.behlegs=0;
//robot.behspeaker=0;
//robot.behears=0;
//robot.behcamera=0;
//robot.behtail=0;
//robot.behlights=0;
};
};
function robot.bored(){
if ((robot.ex==0)  &&
(robot.migrate==1))
{
		robot.ex=1;

if(robot.behlegs==1) {
if(robot.lastB==4){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
robot.SitDown();
};
if(robot.behlights==1) {
modeG.val=1;
modeR.val=0;
modeR.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=1;
ledF10.val=1;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
};
if(robot.behlegs==1) {
legRF1.val=80 time:1000ms &
legRF2.val=5 time:1s &
legFF << legRF3.val=30 sin:1s
ampli:10},
if((ball.visible==0) &&
(robot.behcamera==1))
headTilt.val=44 time:966ms;
if(robot.behspeaker==1){
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;};
stop legFF;
if((ball.visible==0) &&
(robot.behcamera==1))
headTilt.val=20 time:500ms &
if(robot.behlegs==1)legRF2.val=30
time:777ms &
if(robot.behcamera==1)headPan.val=
-30 time:777ms;
if(robot.behlegs==1)legRF2.val=0
time:777ms &
```

```
if(robot.behcamera==1)headPan.val=
0 time:777ms;
if(robot.behlegs==1)legRF2.val=30
time:777ms &
if(robot.behcamera==1)headPan.val=
-30 time:777ms;
if(robot.behlegs==1)legRF2.val=0
time:777ms &
if(robot.behcamera==1)headPan.val=
0 time:777ms;

if(robot.behlegs==1)legRF1.val=25
time:777ms &
if(robot.behlegs==1)legRF3.val=110
time:777ms & if((ball.visible==0)
&&
(robot.behcamera==1))headPan.val=-
39 time:777ms & headTilt.val=-8
time:500ms;

if(robot.behtail==1){
tail11 << tailPan.val=-40 sin:3s
ampli:100},

robot.borvar=1;
var robot.timesbored=0;

every15 << every(15s) {
if(robot.borvar==1) {
if(robot.behspeaker==1){mouth.val=
-30 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms & };
robot.timesbored=robot.timesbored+
1;

if(robot.behtail==1)tailTilt.val=2
time:500ms &  if((ball.visible==0)
&&
(robot.behcamera==1))headTilt.val=
20 time:500ms &
if(robot.behears==1){earL.val=1 &
earR.val=1;};

if(robot.behtail==1)tailTilt.val=62
time:500ms & if((ball.visible==0)
&&
(robot.behcamera==1))headTilt.val=-
8 time:500ms &
if(robot.behears==1)earL.val=0 &
earR.val=0;

if(robot.behtail==1)tailTilt.val=2
time:500ms & if((ball.visible==0)
&&
(robot.behcamera==1))headTilt.val=
20 time:500ms &
if(robot.behears==1)earL.val=1 &
earR.val=1;

if(robot.behtail==1)tailTilt.val=62
time:500ms & if((ball.visible==0)
&&
(robot.behcamera==1))headTilt.val=-
8 time:500ms &
if(robot.behears==1){earL.val=0 &
earR.val=0;};

if(robot.behtail==1)tailTilt.val=30
time:500ms;
};
};
```

```
at (( (robot.timesbored>=2 ||
pawRF.val==1) && legRF1.val>0
&& robot.borvar==1))
{

robot.borvar=0;
if(robot.behspeaker==1){
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;};
stop every15;
stop tail11;

if(robot.behlegs==1)robot.StandUp()
;
robot.lastB=3;
robot.ActionF=10;
robot.ex=0;
//robot.behlegs=0;
//robot.behspeaker=0;
//robot.behears=0;
//robot.behcamera=0;
//robot.behtail=0;
//robot.behlights=0;
};

};
};


function robot.tired(){
if ((robot.ex==0)  &&
(robot.migrate==1))
{
		robot.ex=1;

if((robot.lastB==4) &&
(robot.behlegs==1)){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};

if ((robot.lastB!=1) &&
(robot.behlegs==1))
		robot.StandUp();

if(robot.behspeaker==1)speaker.play
("pup.wav");
if(robot.behlights==1) {
modeG.val=0;
modeR.val=1;
modeB.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
```

```
ledF13.val=0;
ledF14.val=0;
};

if(robot.behtail==1){tail12 <<
tailPan.val=-10 sin:4s ampli:50},

if(robot.behtail==1)tailTilt.val=58
time:500ms & if((ball.visible==0)
&&
(robot.behcamera==1)){headTilt.val
=10 time:1s & neck.val=2 time:1s &
if(ball.visible==0)headPan.val=40
time:2s;};

if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=-
40 time:2s;
if((ball.visible==0) &&
(robot.behcamera==1)){headPan.val
=0 time:1s & headTilt.val=-10
time:1s;};

if((ball.visible==0) &&
(robot.behcamera==1))headTilt.val=
44 time:1s;
if((ball.visible==0) &&
(robot.behcamera==1))headTilt.val=
15 time:1s;

if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;};
if ((robot.lastB!=1) &&
(robot.behlegs==1))
{
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s;
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=90 time:2s &
legRH1.val=-100 time:3s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=90 time:2s &
legLH1.val=-100 time:3s &
legLH2.val=0 time:2s &
legLH3.val=118 time:2s;
};
if(robot.behlegs==1){
legRF1.val=61 time:2s &
legRF2.val=-6 time:2s &
legRF3.val=22 time:2s &
legRH1.val=-134 time:2s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &
legLF1.val=61 time:2s &
legLF2.val=-6 time:2s &
legLF3.val=22 time:2s &
legLH1.val=-134 time:2s &
legLH2.val=0 time:2s &
```

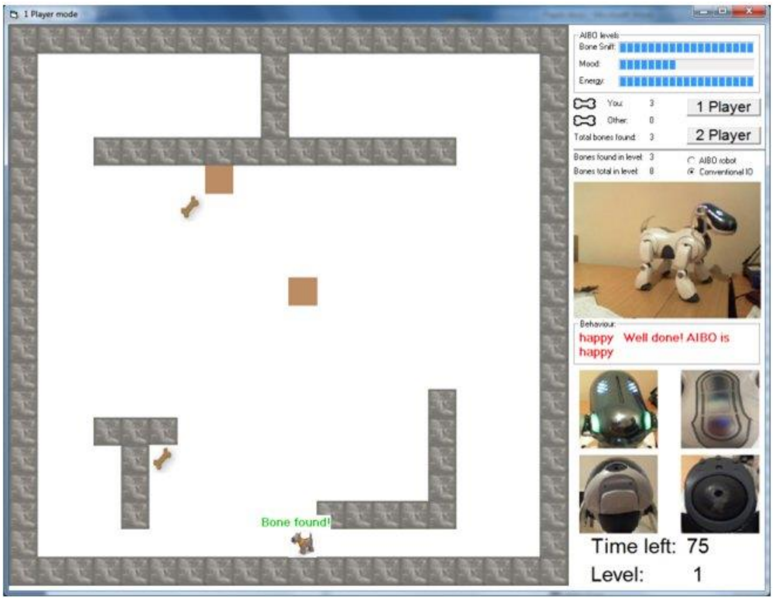
```
legLH3.val=118 time:2s & };
if((ball.visible==0) &&
(robot.behcamera==1))headTilt.val=-
10 time:1s;
if((speaker.playing!=1) &&
(robot.behspeaker==1))speaker.play(
"bark.wav");
robot.lastB=3;
//stopall;
stop tail12;
robot.ActionF=10;
robot.ex=0;
//robot.behlegs=0;
//robot.behspeaker=0;
//robot.behears=0;
//robot.behcamera=0;
//robot.behtail=0;
//robot.behlights=0;
};}};
function robot.friend(){
if ((robot.ex==0)  &&
(robot.migrate==1))
{
                robot.ex=1;

if((robot.lastB!=4) &&
(robot.behlegs==1))robot.StandUp();
if(robot.behlights==1) {
modeG.val=0;
modeR.val=1;
modeB.val=1;

ledF1.val=0;
ledF2.val=0;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
};

if(robot.behtail==1){tail13 <<
tailPan.val=0 sin:1s ampli:20},

if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
hap1.wav");
mouth.val=-6 time:244ms & };
if(robot.behlegs==1){
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s & };
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=-
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=-
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
0 smooth:500ms &

if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
hap2.wav");
mouth.val=-6 time:244ms & };
if(robot.behtail==1){tailTilt.val=2
time:300ms & tailPan.val=10
time:200ms & };
if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
hap2.wav");
mouth.val=-6 time:244ms; };

if((ball.visible==0) &&
(robot.behcamera==1)){headPan.val
=0 time:1s &
neck.val=2 time:1s &
if(ball.visible==0)headTilt.val=-1
time:1s;};
if(robot.behtail==1)tailPan.val=-5
time:333ms & if((ball.visible==0)
&&
(robot.behcamera==1))headTilt.val=
44 time:1500ms;

if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=-
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
20 smooth:700ms;
if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=-
20 smooth:700ms &

if(robot.behears==1){earL.val=1 &
earR.val=1 & };
if(robot.behspeaker==1){mouth.val=
-35 time:333ms &
if(speaker.playing!=1)speaker.play("
hap1.wav");
mouth.val=-6 time:244ms; };

if(robot.behtail==1){earL.val=0 &
earR.val=0;};
if(robot.behtail==1){earL.val=1 &
earR.val=1;};
if(robot.behtail==1){earL.val=0 &
earR.val=0;};
if(robot.behtail==1){earL.val=1 &
earR.val=1;};
if(robot.behtail==1){earL.val=0 &
earR.val=0;};


if((ball.visible==0) &&
(robot.behcamera==1))headPan.val=
0 time:800ms;
robot.lastB=4;
stop tail13;
robot.ActionF=10;
robot.ex=0;
//var robot.behlegs=1;
//var robot.behspeaker=1;
//var robot.behears=1;
//var robot.behcamera=1;
//var robot.behtail=1;
//var robot.behlights=1;
};
};
function robot.end()
{
if ((robot.ex==0)  &&
(robot.migrate==1))
{
waituntil(robot.actionF==10);
                robot.ex=1;
robot.ActionF=9;
if(robot.behcamera==1)headPan.val=
0 smooth:1s;
if((robot.lastB==4) &&
(robot.behlegs==1)){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
if(robot.behlegs==1)robot.SitDown()
;
if(robot.behspeaker==1)speaker.play
("test.wav");
if(robot.behlegs==1){timeout(4s)
legLF3.val'n=0.3 sin:457 ampli:0.1},
if(robot.behlegs==1){timeout(4s)
legRF3.val'n=0.3 sin:457 ampli:0.1},
if(robot.behcamera==1){timeout(4s)
headTilt.val'n = 0.4 sin:457
ampli:0.1;};
robot.ex=0;
robot.gameend=666;
robot.ActionF=10;
robot.game=0;
};}};
function robot.sad()
{
if((robot.ex==0) &&
(robot.migrate==1))
{
robot.ex=1;
if(robot.behlights==1){
modeG.val=0;
modeR.val=1;
modeB.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
};
```

```
if(robot.behlegs==1)robot.StandUp()
;
if(robot.behtail==1){
tailTilt.val=63 smooth:1s &
timeout(15s) tailPan.val=-10 sin:4s
ampli:50},

if(robot.behears==1){
earL.val=0 & earR.val=0;
};
if(robot.behspeaker==1){
mouth.val=-3 &
speaker.play("1.wav") & };
if(robot.behcamera==1){
headTilt.val=10 smooth:2s &
headPan.val=0 smooth:1s &
neck.val=-79 smooth:1s;
headTilt.val=40 smooth:1s;
};
robot.ex=0;
robot.ActionF=10;
};
};
function robot.food()
{
if(robot.ex==0)
{
robot.ex=1;

if(robot.behlegs==1) {
robot.StandUp();
};

if(robot.behlights==1){
modeG.val=1;
modeR.val=0;
modeB.val=0;

ledF1.val=1;
ledF2.val=1;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
};
if(robot.behcamera==1){
neck.val=2 smooth:1s;
headPan.val=-35 smooth:500ms;
};
if(robot.behlegs==1) {
legRF1.val=85 smooth:1500ms &
legRF2.val=0 smooth:1500ms &
legRF3.val=44 smooth:1500ms &
legRH1.val=-56 smooth:1s &
legRH2.val=0 smooth:1s &
legRH3.val=75 smooth:1s &
legLF1.val=85 smooth:1500ms &
legLF2.val=0 smooth:1500ms &
legLF3.val=44 smooth:1500ms &
legLH1.val=-56 smooth:1s &
legLH2.val=0 smooth:1s &
legLH3.val=75 smooth:1s;
};
if(robot.behspeaker==1){
mouth.val=-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };
if(robot.behcamera==1){headPan.val
=35 smooth:1s;};
if(robot.behspeaker==1){
mouth.val=-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };

if(robot.behcamera==1){
headPan.val=0 smooth:500ms;
headTilt.val=44 smooth:500ms & };

if(robot.behears==1){ earL.val=1 &
earR.val=1;};

if(robot.behspeaker==1){mouth.val=
-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };
if(robot.behears==1){ earL.val=0 &
earR.val=0;};
if(robot.behspeaker==1){mouth.val=
-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };
robot.onfood=1;
searchfood:{
whenever (ball.visible ~ 100ms){
headPan.val  = headPan.val + 0.9 *
camera.xfov * ball.x &
headTilt.val = headTilt.val + 0.9 *
camera.yfov * ball.y;
};
};
at (robot.onfood==1 &&
(((headPan.val>-50 &&
headPan.val<-14) || (headPan.val>14
&& headPan.val<50)) &&
headTilt.val<20) ~ 2500ms){
robot.onfood=0;
stop searchfood;
if(headPan.val<0)
robot.choice=1;
if(headPan.val>0)
robot.choice=2;
if(robot.behspeaker==1){mouth.val=
-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };
if(robot.behcamera==1)headTilt.val=
42 smooth:500ms &
if(robot.behspeaker==1){mouth.val=
-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };

if(robot.behcamera==1)headTilt.val=
15 smooth:500ms &
if(robot.behspeaker==1){mouth.val=
-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms; };

if(robot.behcamera==1)headTilt.val=
0 smooth:500ms &
if(robot.behcamera==1)headPan.val=
0 smooth:500ms &

if(robot.behlegs==1) {
legRF1.val=57 time:3s &
legRF2.val=0 time:2s &
legRF3.val=43 time:3s &

legRH1.val=-134 time:4s &
legRH2.val=1 time:1s &
legRH3.val=119 time:2s &

legLF1.val=57 time:3s &
legLF2.val=0 time:2s &
legLF3.val=43 time:3s &

legLH1.val=-134 time:4s &
legLH2.val=1 time:1s &
legLH3.val=119 time:2s;};
};
robot.ex=0;
robot.choice=0;
robot.ActionF=10;
};
};
```

The robot file robot.u can be found under the folder Experiment1

Appendix III: AiBone GUI, linker and AIBO Robot modules

AiBone interface



You: 3
Other: 0
Total bones found: 3
Bones found in level: 3
Bones total in level: 8
○ AIBO robot
● Conventional IO
Behaviour: happy Well done! AIBO is happy
Time left: 75
Level: 1

AiBone interface consists of the Project1.vbp, Form1.frm and Module1.bas files. The interface was developed using Microsoft Visual Basic 6 and the files are located under Experiment1\Interface folder.

AIBOcom linker

The linker consists of dll.dev (project file), dll.h and dll.cpp file and was written in C.

Dll.h:

```
#ifndef _DLL_H_
#define _DLL_H_
#if BUILDING_DLL
# define DLLIMPORT __declspec
(dllexport)
#else /* Not BUILDING_DLL */
# define DLLIMPORT __declspec
(dllimport)
#endif /* Not BUILDING_DLL */
class DLLIMPORT DllClass
{
  public:
    DllClass();
    virtual ~DllClass(void);
  private:
};
extern "C" __declspec( dllexport )
__stdcall int init(void);
extern "C" __declspec( dllexport )
__stdcall int gettir(void);
extern "C" __declspec( dllexport )
__stdcall int getbor(void);
extern "C" __declspec( dllexport )
__stdcall void shut(void);
extern "C" __declspec( dllexport )
__stdcall int fotis(void);
extern "C" __declspec( dllexport )
__stdcall int ballV(void);
extern "C" __declspec( dllexport )
__stdcall int curaction(void);
extern "C" __declspec( dllexport )
__stdcall int exce(int actionn);
extern "C" __declspec( dllexport )
__stdcall int setf(int a1,int a2);
#endif /* _DLL_H_ */
```

Dll.cpp

```
#include "dll.h"
#include <windows.h>
#include "urbi\UClient.hh"
#include "urbi\uabstractclient.hh"
#include "stdio.h"
#include "urbi\ucallbacks.hh"
#include "string"
#include <time.h>
#include <iostream>
#include <sstream>
using namespace urbi;
using namespace std;
float tirCur=0;
float tirCur2=0;
int drives=0;
```

```
int fotios=0;
int curAct=0;
int ball=0;
void sleep(unsigned int mseconds)
{
   clock_t goal = mseconds + clock();
   while (goal > clock());
}
UCallbackAction on1(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            tirCur=(float)ff.val;
            return URBI_CONTINUE;
}
UCallbackAction on2(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            tirCur2=(float)ff.val;
            return URBI_CONTINUE;
}

UCallbackAction on3(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            drives=(int)ff.val;
            return URBI_CONTINUE;
}
UCallbackAction on4(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            curAct=(int)ff.val;
            return URBI_CONTINUE;
}
UCallbackAction on5(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            ball=(int)ff.val;
            return URBI_CONTINUE;
}
UClient * cl= new
UClient("192.168.1.199");
extern "C" __declspec( dllexport )
__stdcall int init(void)
{
cl->setCallback(&on1, "headtilt");
cl->setCallback(&on2, "headpan");
cl->setCallback(&on5, "ballV");
cl->setCallback(&on3, "tired");
cl->setCallback(&on3, "bored");
cl->setCallback(&on4, "curaction");
return 1;
}
extern "C" __declspec( dllexport )
__stdcall int ballV(void)
{
     cl->send("ballV <<
ball.visible;");
     Sleep(80);
     return ball;
}

extern "C" __declspec( dllexport )
__stdcall void shut(void)
{
     cl->send("stopall;");
     Sleep(1000);
     cl->send("robot.LayDown();");
     Sleep(1000);
     cl->send("shutdown;");
}

extern "C" __declspec( dllexport )
__stdcall int gettir(void)
{
     cl->send("tired << robot.tir;");
     Sleep(80);
     return drives;
}
extern "C" __declspec( dllexport )
__stdcall int getbor(void)
{
     cl->send("bored <<
robot.moodvar;");
     Sleep(80);
     return drives;
}
extern "C" __declspec( dllexport )
__stdcall int curaction(void)
{
     int tmpcur=0;

     cl->send("curaction <<
robot.actionF;");
     sleep(80);
     tmpcur=curAct;
     curAct=0;
     return tmpcur;
}
extern "C" __declspec( dllexport )
__stdcall int exce(int actionn)
{
      std::string str1="";
      if(actionn==1)
      str1=("sright();");
      if(actionn==2)
      str1=("sleft();");
      if(actionn==3)
      str1=("stop();");
      if(actionn==4)
      str1=("dig();");
      if(actionn==5)
      str1=("sfront();");
      if(actionn==6)
      str1=("sback();");
      if(actionn==7)
      str1=("happy();");
      if(actionn==8)
      str1=("end();");
      if(actionn==9)
      str1=("active=true;");
      cl->send("robot.");
      sleep(50);
      cl->send(str1.c_str());
    return 0;
}
extern "C" __declspec( dllexport )
__stdcall int setf(int a1,int a2)
{
std::stringstream s;
s << a1;
std::string str1 = s.str();
s.str("");
s << a2;
std::string str2 = s.str();
s.str("");
   cl->send("robot.moodvar=");
   sleep(50);
   cl->send(str1.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   cl->send("robot.tir=");
   sleep(50);
   cl->send(str2.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   return 0;
}
extern "C" __declspec( dllexport )
__stdcall int fotis(void)
{
 int direction=0;
   if (cl->error()) urbi::exit(1);
   cl->send("headtilt <<
headTilt.val;");
   Sleep(50);
   cl->send("headpan <<
headPan.val;");
   Sleep(50);
   //up-down
   if((tirCur>10) &&
(tirCur<=25))direction=12; //headTilt
   if((tirCur>25) &&
(tirCur<=35))direction=10;
   if(tirCur>35)direction=11;

   if((tirCur<5) && (tirCur>=-
1))direction=32;
   if((tirCur<1) && (tirCur>=-
8))direction=30;
   if(tirCur<-8)direction=31;

   //right-left
   if((tirCur2<-10) && (tirCur2>=-
30)) //headPan
          direction=44;
   if((tirCur2<-30) && (tirCur2>=-
45))
      if((direction!=0) &&
(direction!=32) && (direction!=12))
          direction=direction+45;
//55,56,75,76
      else
          direction=40;

   if(tirCur2<-45)
      if((direction!=0) &&
(direction!=32) && (direction!=12))

direction=direction+48;//58,59,78,79
      else
          direction=41;

   if((tirCur2>10) &&
(tirCur2<=30)) //right
          direction=22;

   if((tirCur2>30) &&
(tirCur2<=45))
      if((direction!=0) &&
(direction!=32) && (direction!=12))

direction=direction+16;//26,27,46,47
      else
          direction=20;

   if(tirCur2>45)
      if((direction!=0) &&
(direction!=32) && (direction!=12))

direction=direction+32;//42,43,62,63
      else
          direction=21;
   if((tirCur<=15) && (tirCur>=4)
&& (tirCur2<=15) && (tirCur2>=-
15))direction=0;
   //urbi::execute();
   return direction;
```

```
}
BOOL APIENTRY DllMain
(HINSTANCE hInst     /* Library
instance handle. */ ,
                    DWORD reason
/* Reason this function is being
called. */ ,
                    LPVOID reserved     /*
Not used. */ )
{
   switch (reason)
   {
     case DLL_PROCESS_ATTACH:
       break;

     case DLL_PROCESS_DETACH:
       break;

     case DLL_THREAD_ATTACH:
       break;

     case DLL_THREAD_DETACH:
       break;
   }
   /* Returns TRUE on success,
FALSE on failure */
   return TRUE;
}
```

Robot file

```
var robot.tir=0;
var robot.bor=0;
var robot.fri=0;
var robot.exc=0;
var robot.ActionF=0;
var robot.lastB=0;
var robot.borvar=0;
var robot.excLimit=30;
var robot.tirLimit=60;
var robot.borLimit=40;
var robot.friLimit=30;

var robot.touchtemp=0;
var robot.touchaveg=0;
var robot.touchaveg0=0;
var robot.counttemp=0;
var robot.countaveg=0;


motors on;
wait(1000);
robot.initial();

ball.a = 0.9;
var lastvalPan=0;
var lastvalTilt=0;

// Main behavior
whenever (ball.visible ~ 100ms) {
lastvalPan=headPan.val;
lastvalTilt=headTilt.val;
headPan.val  = headPan.val + ball.a *
camera.xfov * ball.x &
if(headTilt.val<40){
headTilt.val = headTilt.val + ball.a *
camera.yfov * ball.y;}
else
{
headTilt.val = headTilt.val + ball.a *
camera.yfov * ball.y;
neck.val=neck.val +ball.a *
camera.yfov * ball.y;
};

};

at (!ball.visible ~ 100ms)
search: {


                if(lastvalPan<headPan.val
)
                                {

                headPan.val   = 60
smooth:700ms;

                headPan.val   = 0
smooth:1200ms;
                                }
                                &

                if(lastvalTilt<headTilt.val
)
                                {

                headTilt.val=37
smooth:700ms;

                headTilt.val=14
smooth:1200ms;
                                }
                                else
                                {

                if(lastvalPan>headPan.val
)
                                {

                headPan.val=-60
smooth:700ms;

                headPan.val=0
smooth:1200ms;
                                }
                                &

                if(lastvalTilt>headTilt.val
)
                                {

                headTilt.val=-10
smooth:700ms;

                headTilt.val=14
smooth:1200ms;
                };
                                };
        };
at (!ball.visible ~ 2500ms)
{
headPan.val=0 smooth:1s &
headTilt.val=16 smooth:1s;
};

at (ball.visible) stop search;


modeG.val=1;
modeR.val=0;
modeR.val=0;

ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
at(robot.tir==-100)
{
robot.tir=0;
robot.ActionF=5;
robot.end();
};

at(headSensor.val>7)
{
tempcatch << every(10ms){
                whenever(headSensor.val
>7){

                robot.counttemp=robot.co
unttemp+1;

                robot.touchtemp=robot.to
uchtemp+headSensor.val;
                };};

ledF12.val=1 & ledF13.val=1 &
ledF11.val=0;

headPan.val=headPan.val+10
smooth:233ms &
headTilt.val=headTilt.val+6
smooth:233ms &
neck.val=neck.val+10
smooth:233ms;

headPan.val=headPan.val-3
smooth:233ms &
headTilt.val=headTilt.val-1
smooth:233ms;
neck.val=neck.val-6 smooth:233ms;

ledF12.val=0 & ledF13.val=0 &
ledF11.val=0;
}
onleave
{
stop tempcatch;
robot.touchtemp=robot.touchtemp/ro
bot.counttemp;

robot.countaveg=robot.countaveg+1;
robot.touchaveg0=robot.touchaveg0+
robot.touchtemp;
robot.touchaveg=robot.touchaveg0/r
obot.countaveg;

robot.touchtemp;
robot.touchaveg;
```

```
if(robot.touchtemp>robot.touchaveg-
4 &&
robot.touchtemp<robot.touchaveg+4)
{
if(speaker.playing!=1)speaker.play("
happy.wav");
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+8;
if(robot.tir>0)robot.tir=robot.tir-2;
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+4;
if(robot.bor>0)robot.bor=robot.bor-2;

}
else
if(robot.touchtemp>=robot.touchave
g+4)
{
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+5;
if(robot.tir>0)robot.tir=robot.tir-2;
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+2;
//if(robot.bor<robot.borLimit)robot.b
or=robot.bor+1;
if(speaker.playing!=1)speaker.play("
angry.wav");
}
else
{
if(speaker.playing!=1)speaker.play("
att.wav");
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+2;
if(robot.tir>0)robot.tir=robot.tir-1;
//robot.fri=robot.fri+2;
if(robot.bor<robot.borLimit)robot.bo
r+2;
};
robot.counttemp=0;
robot.touchtemp=0;

};

at(chinSensor.val>=1){
if(robot.exc<robot.excLimit)robot.ex
c=robot.exc+15;
if(robot.bor<robot.borLimit)robot.bo
r=robot.bor-3;
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir-2;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at(backSensorF.val>25){
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorM.val>25){
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorR.val>25){
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+10;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorM.val>5 &&
backSensorM.val<=25){
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;

};

at(backSensorF.val>5 &&
backSensorF.val<=25){
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at(backSensorR.val>5 &&
backSensorR.val<=25){
if(robot.fri<robot.friLimit)robot.fri=r
obot.fri+10;
if(robot.bor>0)robot.bor=robot.bor-5;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};


at(headSensor.val>25)
{
if(robot.tir<robot.tirLimit)robot.tir=r
obot.tir+8;
if(robot.bor>0)robot.bor=robot.bor-1;
if(speaker.playing!=1)speaker.play("
angry.wav");
};


every(1500ms){

if((robot.fri>=robot.friLimit) &&
(robot.borvar==0)){
        if (robot.ActionF==0) {

        robot.ActionF=4;
                robot.friend();
        };
};

if((robot.exc>=robot.excLimit) &&
(robot.borvar==0)){
        if (robot.ActionF==0) {

        robot.ActionF=1;
                robot.excite();
        };
};

if((robot.bor>=robot.borLimit) &&
(robot.borvar==0)){
        if (robot.ActionF==0) {

        robot.ActionF=2;
                robot.bored();
        };
};

if((robot.tir>=robot.tirLimit) &&
(robot.borvar==0)){
        if (robot.ActionF==0) {

        robot.ActionF=3;
                robot.tired();
        };
};

if(robot.ActionF==1) //excited
{
        if(robot.exc>14)robot.exc
=robot.exc-3;
        if(robot.bor>8)robot.bor=
robot.bor-4;
        if(robot.tir<40)robot.tir=r
obot.tir+1;
//
        if(robot.fri<robot.friLimit
)robot.fri=robot.fri+1;
}
else if(robot.ActionF==2) //bored
{
        if(robot.exc>3)robot.exc=
robot.exc-1;
        if(robot.bor>3)robot.bor=
robot.bor-3;
        if(robot.tir>5)robot.tir=ro
bot.tir-1;
        if(robot.fri>5)robot.fri=ro
bot.fri-1;
}
else if(robot.ActionF==3)  //tired
{
        if(robot.exc>3)robot.exc=
robot.exc-1;
        //if(robot.bor>5)robot.bor
=robot.bor-1;
        if(robot.tir>7)robot.tir=ro
bot.tir-7;
        //if(robot.fri<25)robot.fri=
robot.fri+1;
}
else if(robot.ActionF==4)  //happy
{
        if(robot.exc<robot.excLi
mit)robot.exc=robot.exc+1;
        //if(robot.bor>5)robot.bor
=robot.bor-1;
        if(robot.tir>4)robot.tir=ro
bot.tir-4;
        if(robot.fri>3)robot.fri=ro
bot.fri-3;
}
else
{
if((robot.exc>0) &&
(ball.visible==1))
robot.exc=robot.exc-1;
```

```
if((robot.bor<robot.borLimit)&&(ball.visible==0))robot.bor=robot.bor+3;
//if((robot.bor<robot.borLimit)&&(ball.visible==1))robot.bor=robot.bor-1;
if((robot.tir<robot.tirLimit)&&(ball.visible==1))robot.tir=robot.tir+2;
if((robot.tir>5)&&(ball.visible==0))robot.tir=robot.tir-3;
if((robot.fri>0) && (ball.visible==0))
robot.fri=robot.fri-1;
};

};

function robot.excite(){
//beg and happy

if(robot.lastB==4){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();

modeG.val=1;
modeR.val=0;
modeB.val=0;

ledF1.val=1;
ledF2.val=1;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;


legRF1.val=85 smooth:1500ms &
legRF2.val=0 smooth:1500ms &
legRF3.val=44 smooth:1500ms &
legRH1.val=-56 smooth:1s &
legRH2.val=0 smooth:1s &
legRH3.val=75 smooth:1s &
legLF1.val=85 smooth:1500ms &
legLF2.val=0 smooth:1500ms &
legLF3.val=44 smooth:1500ms &
legLH1.val=-56 smooth:1s &
legLH2.val=0 smooth:1s &
legLH3.val=75 smooth:1s &
if(speaker.playing!=1)speaker.play("bark.wav") &
if(ball.visible==0) headTilt.val=44
smooth:1s &
if(ball.visible==0) headPan.val=30
smooth:1s &
neck.val=2 smooth:1s;
tailTilt.val=40 time:500ms &
tailmov << tailPan.val=-40 sin:3s
ampli:100,
headTilt.val=21 time:333ms &
if(ball.visible==0)headPan.val=-60
time:1s & mouth.val=-35
time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav");
mouth.val=-6 time:244ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms &
if(ball.visible==0)headPan.val=60
time:1866ms & mouth.val=-35
time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav") &
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
mouth.val=-6 time:144ms &
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;
legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms  &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
legLH2.val=0 time:150ms &
legLF2.val=0 &
legRH2.val=0 time:150ms &
legRF2.val=0;
if(ball.visible==0)headPan.val=0
time:666ms &
if(ball.visible==0)headTilt.val=44
time:1s & neck.val=2 time:1s;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav");
mouth.val=-6 time:244ms;
earL.val=1 & earR.val=1 &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav");
earL.val=0 & earR.val=0 &
mouth.val=-6 time:244ms;
legRF1.val=57 time:3s &
legRF2.val=0 time:2s &
legRF3.val=43 time:3s &
legRH1.val=-134 time:4s &
legRH2.val=1 time:1s &
legRH3.val=119 time:2s &

legLF1.val=57 time:3s &
legLF2.val=0 time:2s &
legLF3.val=43 time:3s &

legLH1.val=-134 time:4s &
legLH2.val=1 time:1s &
legLH3.val=119 time:2s &
earL.val=0 & earR.val=0 &

{if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;};

neck.val=0 time:2s &
earL.val=1 & earR.val=1 &

if(ball.visible==0)headTilt.val=-5
time:1s &
if(ball.visible==0)headPan.val=0
time:1s & neck.val=2 time:1s &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav");
mouth.val=-6 time:244ms;
//stopall;
robot.lastB=1;
stop tailmov;
robot.ActionF=0;
};

function robot.bored(){

if(robot.lastB==4){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};

robot.SitDown();
modeG.val=1;
modeR.val=0;
modeR.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
```

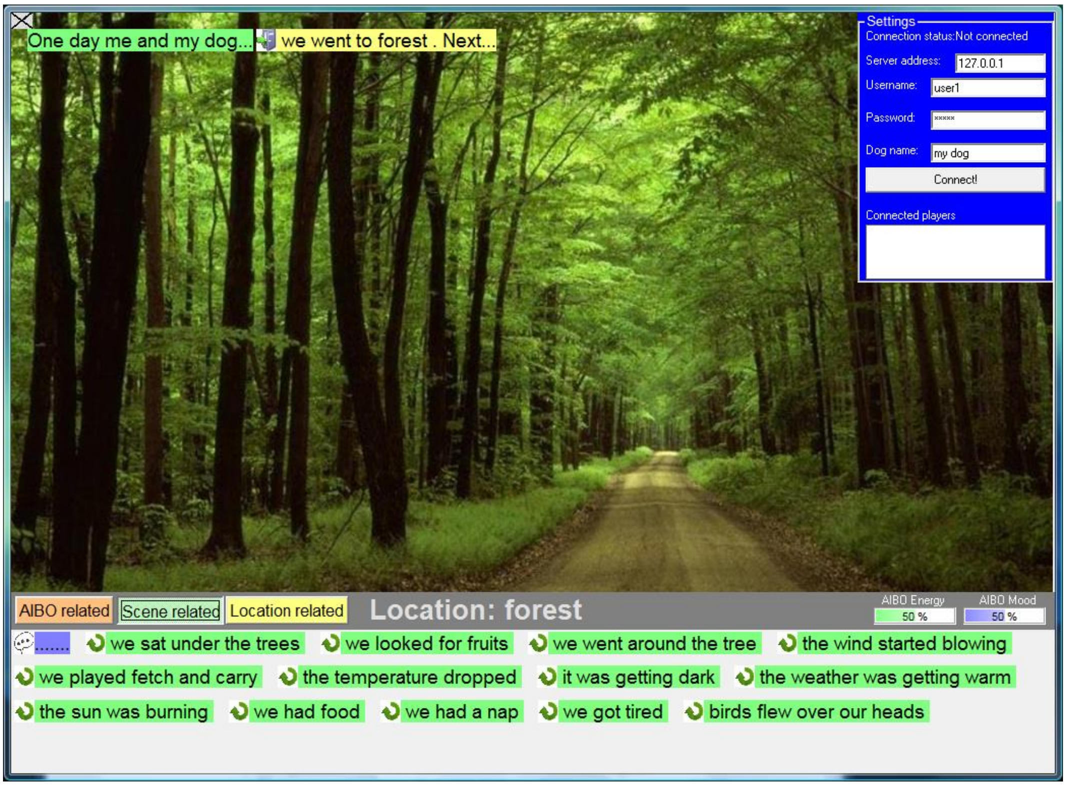
```
ledF7.val=1;
ledF8.val=1;
ledF9.val=1;
ledF10.val=1;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;


legRF1.val=80 time:1000ms &
legRF2.val=5 time:1s &
legFF << legRF3.val=30 sin:1s
ampli:10,

if(ball.visible==0)headTilt.val=44
time:966ms;

mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
stop legFF;
if(ball.visible==0)headTilt.val=20
time:500ms & legRF2.val=30
time:777ms & headPan.val=-30
time:777ms;
legRF2.val=0 time:777ms &
headPan.val=0 time:777ms;
legRF2.val=30 time:777ms &
headPan.val=-30 time:777ms;
legRF2.val=0 time:777ms &
headPan.val=0 time:777ms;

legRF1.val=25 time:777ms &
legRF3.val=110 time:777ms &
if(ball.visible==0)headPan.val=-39
time:777ms & headTilt.val=-8
time:500ms;

tail11 << tailPan.val=-40 sin:3s
ampli:100,
robot.borvar=1;
var robot.timesbored=0;

every15 << every(15s) {
if(robot.borvar==1) {
mouth.val=-30 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav") ;
mouth.val=-6 time:444ms &
robot.timesbored=robot.timesbored+
1;
tailTilt.val=2 time:500ms &
if(ball.visible==0)headTilt.val=20
time:500ms & earL.val=1 &
earR.val=1;
tailTilt.val=62 time:500ms &
if(ball.visible==0)headTilt.val=-8
time:500ms & earL.val=0 &
earR.val=0;
tailTilt.val=2 time:500ms &
if(ball.visible==0)headTilt.val=20
time:500ms & earL.val=1 &
earR.val=1;
tailTilt.val=62 time:500ms &
if(ball.visible==0)headTilt.val=-8
time:500ms & earL.val=0 &
earR.val=0;
tailTilt.val=30 time:500ms;
};
};

at (( (robot.timesbored==2 ||
pawRF.val==1) && legRF1.val>0
&& robot.borvar==1))
{
robot.borvar=0;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
stop every15;
stop tail11;
robot.StandUp();
robot.lastB=3;
robot.ActionF=0;
};
};


function robot.tired(){
if(robot.lastB==4){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};

if (robot.lastB!=1)
        robot.StandUp();

speaker.play("pup.wav");
modeG.val=0;
modeR.val=1;
modeB.val=0;

ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
tail12 << tailPan.val=-10 sin:4s
ampli:50,
tailTilt.val=58 time:500ms &
if(ball.visible==0)headTilt.val=10
time:1s & neck.val=2 time:1s &
if(ball.visible==0)headPan.val=60
time:2s;
if(ball.visible==0)headPan.val=-60
time:2s;
if(ball.visible==0)headPan.val=0
time:1s & headTilt.val=-10 time:1s;
if(ball.visible==0)headTilt.val=44
time:1s;
if(ball.visible==0)headTilt.val=15
time:1s;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
if (robot.lastB!=1)
{
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s;
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=90 time:2s &
legRH1.val=-100 time:3s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=90 time:2s &
legLH1.val=-100 time:3s &
legLH2.val=0 time:2s &
legLH3.val=118 time:2s;
};

legRF1.val=61 time:2s &
legRF2.val=-6 time:2s &
legRF3.val=22 time:2s &

legRH1.val=-134 time:2s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &

legLF1.val=61 time:2s &
legLF2.val=-6 time:2s &
legLF3.val=22 time:2s &

legLH1.val=-134 time:2s &
legLH2.val=0 time:2s &
legLH3.val=118 time:2s &

if(ball.visible==0)headTilt.val=-10
time:1s;
if(speaker.playing!=1)speaker.play("
bark.wav");

robot.lastB=3;
//stopall;
stop tail12;
robot.ActionF=0;
};
function robot.friend(){
if(robot.lastB!=4){
robot.StandUp();
};
modeG.val=0;
modeR.val=1;
modeB.val=1;
ledF1.val=0;
ledF2.val=0;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
```

```
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
tail13 << tailPan.val=0 sin:1s
ampli:20,
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=0
smooth:500ms &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s &
tailTilt.val=2 time:300ms &
tailPan.val=10 time:200ms &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms;

if(ball.visible==0)headPan.val=0
time:1s &
neck.val=2 time:1s &
if(ball.visible==0)headTilt.val=-1
time:1s;
tailPan.val=-5 time:333ms &
if(ball.visible==0)headTilt.val=44
time:1500ms;

if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms &

earL.val=1 & earR.val=1 &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms;
earL.val=0 & earR.val=0;
earL.val=1 & earR.val=1;
earL.val=0 & earR.val=0;
earL.val=1 & earR.val=1;
earL.val=0 & earR.val=0;
if(ball.visible==0)headPan.val=0
time:800ms;
robot.lastB=4;
stop tail13;
robot.ActionF=0;
};

function robot.end()
{
headPan.val=0 smooth:1s;
if(robot.lastB==4){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
robot.SitDown();
speaker.play("test.wav");
timeout(4s) legLF3.val'n=0.3 sin:457
ampli:0.1,
timeout(4s) legRF3.val'n=0.3 sin:457
ampli:0.1,
timeout(4s) headTilt.val'n = 0.4
sin:457 ampli:0.1;
stopall;
};
```

The robot file robot.u can be found under the folder Experiment2

Appendix IV: AIBOStory GUI, Server, linker and AIBO Robot modules

AIBOStory client interface



One day me and my dog... we went to forest . Next...

Settings

Connection status:Not connected

Server address: 127.0.0.1

Username: user1

Password: *****

Dog name: my dog

Connected players

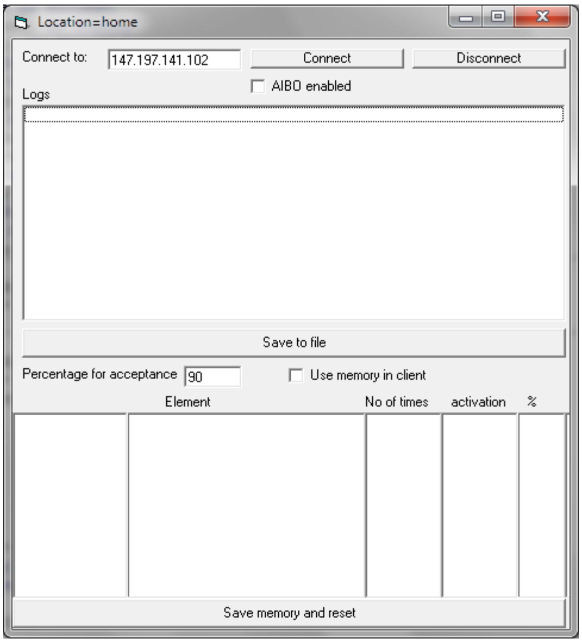
Location: forest

AIBO Energy 50 %

AIBO Mood 50 %

AIBOStory interface consists of the Project1.vbp, Form1.frm, Module1.bas and UserControl1.ctl files. The interface was developed using Microsoft Visual Basic 6 and the files are located under Experiment3\Interface\Client folder.

AIBOStory server interface



Connect to: 147.197.141.102

Percentage for acceptance 90

AIBOStory interface consists of the Project1.vbp, Form1.frm, Module1.bas and functions.bas files. The interface was developed using Microsoft Visual Basic 6 and the files are located under Experiment3\Interface\Server folder.

AIBOcom linker

The linker consists of dll.dev (project file), dll.h and dll.cpp file and was written in C.

Dll.h:

```
#ifndef _DLL_H_
#define _DLL_H_
#if BUILDING_DLL
# define DLLIMPORT __declspec
(dllexport)
#else /* Not BUILDING_DLL */
# define DLLIMPORT __declspec
(dllimport)
#endif /* Not BUILDING_DLL */
class DLLIMPORT DllClass
{
  public:
    DllClass();
    virtual ~DllClass(void);
  private:
};
extern "C" __declspec( dllexport )
__stdcall void init(void);
extern "C" __declspec( dllexport )
__stdcall void shut(void);
extern "C" __declspec( dllexport )
__stdcall int exce(int actionn);
extern "C" __declspec( dllexport )
__stdcall int getenergy(void);
extern "C" __declspec( dllexport )
__stdcall int getmood(void);
extern "C" __declspec( dllexport )
__stdcall int setf(int a1,int a2);
#endif /* _DLL_H_ */
```

Dll.cpp

```
#include "dll.h"
#include <windows.h>
#include "urbi\UClient.hh"
#include "urbi\uabstractclient.hh"
#include "stdio.h"
#include "urbi\ucallbacks.hh"
#include "string"
#include <time.h>
#include <iostream>
#include <sstream>
using namespace urbi;
using namespace std;
int tirvar=0;
int moodvar=0;
void sleep(unsigned int mseconds)
{
   clock_t goal = mseconds + clock();
   while (goal > clock());
}
UCallbackAction on1(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            tirvar=(int)ff.val;
            return URBI_CONTINUE;
}
UCallbackAction on2(const
UMessage &msg) {
            UValue ff=
*(UValue*)msg.value;
            moodvar=(int)ff.val;
            return URBI_CONTINUE;
}
UClient * cl= new
UClient("147.197.141.200");

extern "C" __declspec( dllexport )
__stdcall void init(void)
{
      cl->setCallback(&on1,
"tirvar1");
      cl->setCallback(&on2,
"moodvar1");
      cl->send("robot.active=1;");
      //sleep(100);
      //cl->send("moodvar1 <<
robot.moodvar;");
      //sleep(100);
      //cl->send("tirvar1 <<
robot.tir;");
}

extern "C" __declspec( dllexport )
__stdcall void shut(void)
{
      cl->send("stopall;");
      Sleep(1000);
```

```
    cl->send("robot.LayDown();");
    Sleep(1000);
    cl->send("shutdown;");
}
extern "C" __declspec( dllexport ) __stdcall int getmood(void)
{
    cl->send("moodvar1 << robot.moodvar;");
    Sleep(80);
    return moodvar;
}
extern "C" __declspec( dllexport ) __stdcall int getenergy(void)
{
    cl->send("tirvar1 << robot.tir;");
    Sleep(80);
    return tirvar;
}
extern "C" __declspec( dllexport ) __stdcall int exce(int actionn)
{
     std::string str1="";
     if(actionn==1)
     str1=("bored(),");
     if(actionn==2)
     str1=("friend(),");
     if(actionn==3)
     str1=("excite(),");
     if(actionn==4)
     str1=("tired(),");
     if(actionn==5)
     str1=("dig(),");
     if(actionn==6)
     str1=("sfront(),");
     if(actionn==7)
     str1=("sad(),");
     if(actionn==8)
     str1=("end(),");
     if(actionn==0)
     str1=("active=0;");
     if(actionn==9)
     str1=("fwd(),");
     if(actionn==10)
     str1=("bwd(),");
     if(actionn==11)
     str1=("rot(),");
     if(actionn==12)
     str1=("sitd(),");
     if(actionn==13)
     str1=("standu(),");
     if(actionn==14)
     str1=("bark(),");
     if(actionn==15)
     str1=("ball(),");
     if(actionn==16)
     str1=("layd(),");
     cl->send("robot.");
     sleep(50);
     cl->send(str1.c_str());
   return 0;
}
extern "C" __declspec( dllexport ) __stdcall int setf(int a1,int a2)
{
std::stringstream s;
s << a1;
std::string str1 = s.str();
s.str("");
s << a2;
std::string str2 = s.str();
s.str("");
   cl->send("robot.moodvar=");
   sleep(50);
   cl->send(str1.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);
   cl->send("robot.tir=");
   sleep(50);
   cl->send(str2.c_str());
   sleep(50);
   cl->send(";");
   sleep(50);

   return 0;
}

BOOL APIENTRY DllMain (HINSTANCE hInst /* Library instance handle. */ ,
            DWORD reason /* Reason this function is being called. */ ,
            LPVOID reserved /* Not used. */ )
{
   switch (reason)
   {
     case DLL_PROCESS_ATTACH:
       break;

     case DLL_PROCESS_DETACH:
       break;

     case DLL_THREAD_ATTACH:
       break;

     case DLL_THREAD_DETACH:
       break;
   }

   /* Returns TRUE on success, FALSE on failure */
   return TRUE;
}
```

Robot file

```
var robot.actionF=0;
var robot.ex=0;
var robot.LactionF=0;
var robot.active=0;
var robot.tir=100;
var robot.moodvar=80;
var robot.tirLimit=100;
var robot.moodLimit=100;
//head sensor values
var robot.touchtemp=0;
var robot.touchaveg=0;
var robot.touchaveg0=0;
var robot.counttemp=0;
var robot.countaveg=0;
var ball.a = 0.9;
var robot.lastvalPan=0;
var robot.lastvalTilt=0;
var robot.intransit=0;
var robot.turning=0;
freeze fotis;
var robot.tosave;
var robot.ontime;
motors on;
wait(1000);
robot.initial();
at((headSensor.val>4) && (headSensor.val<=25))
{
robot.tosave=robot.tosave + " NEW:" + time() + " HEAD VAL:" + headSensor.val;
tempcatch << every(10ms){
          whenever(headSensor.val>7){

          robot.counttemp=robot.counttemp+1;

          robot.touchtemp=robot.touchtemp+headSensor.val;
          };};

ledF12.val=1 & ledF13.val=1 & ledF11.val=0;

headPan.val=headPan.val+10 smooth:233ms &
headTilt.val=headTilt.val+6 smooth:233ms &
neck.val=neck.val+10 smooth:233ms;

headPan.val=headPan.val-3 smooth:233ms &
headTilt.val=headTilt.val-1 smooth:233ms;
neck.val=neck.val-6 smooth:233ms;
//increase energy as well
if(robot.tir<100)robot.tir=robot.tir+1;

ledF12.val=0 & ledF13.val=0 & ledF11.val=0;
}
onleave
{
stop tempcatch;
robot.touchtemp=robot.touchtemp/robot.counttemp;
robot.countaveg=robot.countaveg+1;
robot.touchaveg0=robot.touchaveg0+robot.touchtemp;
robot.touchaveg=robot.touchaveg0/robot.countaveg;
if(robot.touchtemp>robot.touchaveg-4 && robot.touchtemp<robot.touchaveg+4)
{
if(speaker.playing!=1)speaker.play("happy.wav");
if(robot.moodvar<=robot.moodLimit-10)
robot.moodvar=robot.moodvar+10
else
robot.moodvar=robot.moodLimit;
}
else
if(robot.touchtemp>=robot.touchaveg+4)
{
if(speaker.playing!=1)speaker.play("angry.wav");
if(robot.moodvar<=robot.moodLimit-4)
robot.moodvar=robot.moodvar+4
else
robot.moodvar=robot.moodLimit;
```

```
}
else
{
if(speaker.playing!=1)speaker.play("
att.wav");
if(robot.moodvar<=robot.moodLimit
-6)
robot.moodvar=robot.moodvar+6
else
robot.moodvar=robot.moodLimit;
};
robot.tosave=robot.tosave + " NEW:"
+ time() + " TouchC:" +
robot.counttemp;
robot.tosave=robot.tosave + " NEW:"
+ time() + " TouchV:" +
robot.touchtemp;

robot.counttemp=0;
robot.touchtemp=0;
};


at(chinSensor.val>=1)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " CHIN VAL:" +
chinSensor.val;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
if(robot.moodvar<=robot.moodLimit
-15)
robot.moodvar=robot.moodvar+15
else
robot.moodvar=robot.moodLimit;
//increase energy as well
if(robot.tir<100)robot.tir=robot.tir+1;
headTilt.val=20 smooth:200ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
headTilt.val=14 smooth:500ms &
};

at(backSensorF.val>25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacF VAL:" +
backSensorF.val;
if(robot.tir>2)
robot.tir=robot.tir-2
else
robot.tir=0;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorM.val>25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacM VAL:" +
backSensorM.val;
if(robot.tir>2)
robot.tir=robot.tir-2
else
robot.tir=0;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorR.val>25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacR VAL:" +
backSensorR.val;
if(robot.tir>2)
robot.tir=robot.tir-2
else
robot.tir=0;
if(speaker.playing!=1)speaker.play("
angry.wav");
};

at(backSensorM.val>5 &&
backSensorM.val<=25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacM VAL:" +
backSensorM.val;
if(robot.moodvar<=robot.moodLimit
-5)
robot.moodvar=robot.moodvar+5
else
robot.moodvar=robot.moodLimit;
//increase energy as well
if(robot.tir<100)robot.tir=robot.tir+1;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at(backSensorF.val>5 &&
backSensorF.val<=25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacF VAL:" +
backSensorF.val;
if(robot.moodvar<=robot.moodLimit
-5)
robot.moodvar=robot.moodvar+5
else
robot.moodvar=robot.moodLimit;
//increase energy as well
if(robot.tir<100)robot.tir=robot.tir+1;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at(backSensorR.val>5 &&
backSensorR.val<=25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " BacR VAL:" +
backSensorR.val;
if(robot.moodvar<=robot.moodLimit
-5)
robot.moodvar=robot.moodvar+5
else
robot.moodvar=robot.moodLimit;
//increase energy as well
if(robot.tir<100)robot.tir=robot.tir+1;
headTilt.val=30 smooth:300ms &
tailPan.val=-25 smooth:333ms &
if(speaker.playing!=1)speaker.play("
happy.wav");
headTilt.val=20 smooth:300ms &
tailPan.val=25 smooth:333ms;
tailPan.val=-25 smooth:333ms;
};

at(headSensor.val>25)
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " HEAD VAL:" +
headSensor.val;
if(robot.tir>2)
        robot.tir=robot.tir-2
else
        robot.tir=0;

if(speaker.playing!=1)speaker.play("
angry.wav");
};
at(robot.active==1)
{
robot.StandUp();
//logging
robot.tosave="Start " + time();
robot.ontime=time();
};
at(robot.active==0)robot.LayDown();

every(2000ms){

if((robot.actionF==0) &&
(robot.active==1))//=just active
{
if(robot.moodvar>1)robot.moodvar=r
obot.moodvar-1;
if(robot.tir>0)robot.tir=robot.tir-1;
};
if((robot.ex==1) &&
(robot.active==1)) //it executes a
behavior
{
if(robot.actionF==1) //=bored
{
        if(robot.moodvar<robot.m
oodLimit-
24)robot.moodvar=robot.moodvar+1
0;
        if(robot.tir<robot.tirLimit-
2)robot.tir=robot.tir+2;
}
else if(robot.actionF==2)  //=happy
{
        if(robot.moodvar>13)robo
t.moodvar=robot.moodvar-3;
        if(robot.tir>11)robot.tir=r
obot.tir-1;
}
else if(robot.actionF==3) //=excited
{
        if(robot.moodvar>14)robo
t.moodvar=robot.moodvar-4;
        if(robot.tir>11)robot.tir=r
obot.tir-2;
}
else if(robot.actionF==4) //=tired
{
        if(robot.moodvar>11)robo
t.moodvar=robot.moodvar-1;
        if(robot.tir<robot.tirLimit-
20)robot.tir=robot.tir+20;
}
else if(robot.actionF==5) //=dig
{
        if(robot.moodvar<robot.m
oodLimit-
21)robot.moodvar=robot.moodvar+2;
        if(robot.tir>12)robot.tir=r
obot.tir-3;
}
```

```
else if(robot.actionF==6) //=point down
{
	if(robot.moodvar<robot.moodLimit-21)robot.moodvar=robot.moodvar+1;
}
else if(robot.actionF==7) //=sad
{
	if(robot.moodvar>12)robot.moodvar=robot.moodvar-2;
	if(robot.tir>11)robot.tir=robot.tir-1;
}
else if(robot.actionF==9) //=walk fwd
{
	if(robot.moodvar<robot.moodLimit-22)robot.moodvar=robot.moodvar+2;
	if(robot.tir>12)robot.tir=robot.tir-2;
}
else if(robot.actionF==10) //=walk bwd
{
	if(robot.moodvar<robot.moodLimit-22)robot.moodvar=robot.moodvar+2;
	if(robot.tir>12)robot.tir=robot.tir-2;
}
else if(robot.actionF==11) //=rotate
{
	if(robot.moodvar<robot.moodLimit-22)robot.moodvar=robot.moodvar+3;
	if(robot.tir>14)robot.tir=robot.tir-4;
}
else if(robot.actionF==12) //=sit down
{
	if(robot.moodvar<robot.moodLimit-11)robot.moodvar=robot.moodvar+1;
	if(robot.tir<robot.tirLimit-12)robot.tir=robot.tir+3;
}
else if(robot.actionF==13) //=stand up
{
	if(robot.moodvar>11)robot.moodvar=robot.moodvar-1;
	if(robot.tir>11)robot.tir=robot.tir-1;
}
else if(robot.actionF==14) //=bark
{
	if(robot.moodvar<robot.moodLimit-12)robot.moodvar=robot.moodvar+2;
	if(robot.tir>11)robot.tir=robot.tir-1;
}
else if(robot.actionF==15) //=ball
{
	if(robot.moodvar<robot.moodLimit-23)robot.moodvar=robot.moodvar+3;
	if(robot.tir>14)robot.tir=robot.tir-3;
}
else if(robot.actionF==16) //=lay down
{
	//if(robot.moodvar<robot.moodLimit-11)robot.moodvar=robot.moodvar+1;
	if(robot.tir<robot.tirLimit-18)robot.tir=robot.tir+8;
};
};
};
function robot.excite(){
robot.tosave=robot.tosave + " NEW:" + time() + " excite";
//beg and happy
waituntil(robot.ex==0);
robot.ex=1;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();
echo("Start: " + time()/1000);
robot.actionF=3;
modeG.val=1;
modeR.val=0;
modeB.val=0;
ledF1.val=1;
ledF2.val=1;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
legRF1.val=85 smooth:1500ms &
legRF2.val=0 smooth:1500ms &
legRF3.val=44 smooth:1500ms &
legRH1.val=-56 smooth:1s &
legRH2.val=0 smooth:1s &
legRH3.val=75 smooth:1s &
legLF1.val=85 smooth:1500ms &
legLF2.val=0 smooth:1500ms &
legLF3.val=44 smooth:1500ms &
legLH1.val=-56 smooth:1s &
legLH2.val=0 smooth:1s &
legLH3.val=75 smooth:1s &
if(speaker.playing!=1)speaker.play("bark.wav") &

if(ball.visible==0) headTilt.val=44 smooth:1s &
if(ball.visible==0) headPan.val=30 smooth:1s &
neck.val=2 smooth:1s;

tailTilt.val=40 time:500ms &

tailmov << tailPan.val=-40 sin:3s ampli:100,
headTilt.val=21 time:333ms &
if(ball.visible==0)headPan.val=-60 time:1s & mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav");
mouth.val=-6 time:244ms;
legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms &

if(ball.visible==0)headPan.val=60 time:1866ms & mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("bark.wav") &

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;

mouth.val=-6 time:144ms &

legLH2.val=-5 time:350ms &
legLF2.val=-1 time:350ms &
legRH2.val=5 time:350ms &
legRF2.val=1 time:350ms;

legLH2.val=5 time:350ms &
legLF2.val=1 time:350ms &
legRH2.val=-5 time:350ms &
legRF2.val=-1 time:350ms;
```

```
legLH2.val=0 time:150ms &
legLF2.val=0 &
legRH2.val=0 time:150ms &
legRF2.val=0;

if(ball.visible==0)headPan.val=0
time:666ms &
if(ball.visible==0)headTilt.val=44
time:1s & neck.val=2 time:1s;

mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms;
earL.val=1 & earR.val=1 &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
earL.val=0 & earR.val=0 &
mouth.val=-6 time:244ms;

legRF1.val=57 time:3s &
legRF2.val=0 time:2s &
legRF3.val=43 time:3s &

legRH1.val=-134 time:4s &
legRH2.val=1 time:1s &
legRH3.val=119 time:2s &

legLF1.val=57 time:3s &
legLF2.val=0 time:2s &
legLF3.val=43 time:3s &

legLH1.val=-134 time:4s &
legLH2.val=1 time:1s &
legLH3.val=119 time:2s &
earL.val=0 & earR.val=0 &

{if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;};

neck.val=0 time:2s &
earL.val=1 & earR.val=1 &

headTilt.val=-5 time:1s &
headPan.val=0 time:1s & neck.val=2
time:1s &

mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms;
stop tailmov;
robot.ex=0;
robot.actionF=0;
echo("End: " + time()/1000);
robot.LactionF=3;
};
function robot.bored(){
robot.tosave=robot.tosave + " NEW:"
+ time() + " bored";
waituntil(robot.ex==0);
robot.ex=1;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
robot.actionF=1;
echo("Start: " + time()/1000);
robot.SitDown();
modeG.val=1;
modeR.val=0;
modeR.val=0;
ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=1;
ledF10.val=1;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
legRF1.val=80 time:1000ms &
legRF2.val=5 time:1s &
legFF << legRF3.val=30 sin:1s
ampli:10,
if(ball.visible==0)headTilt.val=44
time:966ms;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
stop legFF;
if(ball.visible==0)headTilt.val=20
time:500ms & legRF2.val=30
time:777ms & headPan.val=-30
time:777ms;
legRF2.val=0 time:777ms &
headPan.val=0 time:777ms;
legRF2.val=30 time:777ms &
headPan.val=-30 time:777ms;
legRF2.val=0 time:777ms &
headPan.val=0 time:777ms;

legRF1.val=25 time:777ms &
legRF3.val=110 time:777ms &
if(ball.visible==0)headPan.val=-39
time:777ms & headTilt.val=-8
time:500ms;

tail11 << tailPan.val=-40 sin:3s
ampli:100,
robot.borvar=1;
var robot.timesbored=0;

every15 << every(15s) {
if(robot.borvar==1) {
mouth.val=-30 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav") ;
mouth.val=-6 time:444ms &
robot.timesbored=robot.timesbored+
1;
tailTilt.val=2 time:500ms &
if(ball.visible==0)headTilt.val=20
time:500ms & earL.val=1 &
earR.val=1;
tailTilt.val=62 time:500ms &
if(ball.visible==0)headTilt.val=-8
time:500ms & earL.val=0 &
earR.val=0;
tailTilt.val=2 time:500ms &
if(ball.visible==0)headTilt.val=20
time:500ms & earL.val=1 &
earR.val=1;
tailTilt.val=62 time:500ms &
if(ball.visible==0)headTilt.val=-8
time:500ms & earL.val=0 &
earR.val=0;
tailTilt.val=30 time:500ms;
};
};
at (( (robot.timesbored==2 ||
pawRF.val==1) && legRF1.val>0
&& robot.borvar==1))
{

robot.borvar=0;
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
stop every15;
stop tail11;
echo("End: " + time()/1000);
robot.actionF=0;
robot.StandUp();
robot.ex=0;
robot.LactionF=1;
};
};
function robot.tired(){
robot.tosave=robot.tosave + " NEW:"
+ time() + " tired";
waituntil(robot.ex==0);
robot.ex=1;
robot.tir=50;

if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();
echo("start: " + time()/1000);
robot.actionF=4;
speaker.play("pup.wav");
modeG.val=0;
modeR.val=1;
modeB.val=0;

ledF1.val=0;
ledF2.val=0;
ledF3.val=0;
ledF4.val=0;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
```

```
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
tail12 << tailPan.val=-10 sin:4s
ampli:50,
tailTilt.val=58 time:500ms &
if(ball.visible==0)headTilt.val=10
time:1s & neck.val=2 time:1s &
if(ball.visible==0)headPan.val=60
time:2s;
if(ball.visible==0)headPan.val=-60
time:2s;
if(ball.visible==0)headPan.val=0
time:1s & headTilt.val=-10 time:1s;
if(ball.visible==0)headTilt.val=44
time:1s;
if(ball.visible==0)headTilt.val=15
time:1s;

mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:444ms;
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s;
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=90 time:2s &
legRH1.val=-100 time:3s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=90 time:2s &
legLH1.val=-100 time:3s &
legLH2.val=0 time:2s &
legLH3.val=118 time:2s;
legRF1.val=61 time:2s &
legRF2.val=-6 time:2s &
legRF3.val=22 time:2s &
legRH1.val=-134 time:2s &
legRH2.val=0 time:2s &
legRH3.val=118 time:2s &
legLF1.val=61 time:2s &
legLF2.val=-6 time:2s &
legLF3.val=22 time:2s &
legLH1.val=-134 time:2s &
legLH2.val=0 time:2s &
legLH3.val=118 time:2s &
headTilt.val=-10 time:1s;
if(speaker.playing!=1)speaker.play("
bark.wav");
stop tail12;
robot.ex=0;
robot.actionF=0;
robot.LactionF=4;
};
function robot.friend(){
robot.tosave=robot.tosave + " NEW:"
+ time() + " friend";
waituntil(robot.ex==0);
robot.ex=1;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();
echo("Start: " + time()/1000);
robot.actionF=2;

modeG.val=0;
modeR.val=1;
modeB.val=1;

ledF1.val=0;
ledF2.val=0;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=1;
ledF8.val=1;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
tail13 << tailPan.val=0 sin:1s
ampli:20,
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=20
smooth:700ms;
if(ball.visible==0)headPan.val=-20
smooth:700ms;
if(ball.visible==0)headPan.val=0
smooth:500ms &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
legRF1.val=0 time:1s &
legRF2.val=2 time:1s &
legRF3.val=66 time:1s &
legRH1.val=-38 time:1s &
legRH2.val=2 time:1s &
legRH3.val=72 time:1s &
legLF1.val=0 time:1s &
legLF2.val=2 time:1s &
legLF3.val=66 time:1s &
legLH1.val=-38 time:1s &
legLH2.val=2 time:1s &
legLH3.val=72 time:1s &
tailTilt.val=2 time:300ms &
tailPan.val=10 time:200ms &
mouth.val=-35 time:333ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms;
headPan.val=0 time:1s &
neck.val=2 time:1s & headTilt.val=-1
time:1s;
tailPan.val=-5 time:333ms &
headTilt.val=44 time:1500ms;
headPan.val=20 smooth:700ms;
headPan.val=-20 smooth:700ms;
headPan.val=20 smooth:700ms;
headPan.val=-20 smooth:700ms &
earL.val=1 & earR.val=1 &
mouth.val=-35 time:333ms &
speaker.play("bark.wav");
mouth.val=-6 time:244ms;
earL.val=0 & earR.val=0;
earL.val=1 & earR.val=1;
earL.val=0 & earR.val=0;
earL.val=1 & earR.val=1;
earL.val=0 & earR.val=0;
headPan.val=0 time:800ms;
stop tail13;
robot.ex=0;
robot.fwalk();
echo("End: " + time()/1000);
robot.actionF=0;
robot.LactionF=2;
};


function robot.end()
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " ending";
waituntil(robot.ex==0);

headPan.val=0 smooth:1s;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
robot.SitDown();
robot.actionF=8;
speaker.play("test.wav");
timeout(4s) legLF3.val'n=0.3 sin:457
ampli:0.1,
timeout(4s) legRF3.val'n=0.3 sin:457
ampli:0.1,
timeout(4s) headTilt.val'n = 0.4
sin:457 ampli:0.1;
robot.LayDown();


robot.actionF=0;
robot.LactionF=8;
robot.tosave=robot.tosave + " END:"
+ time();
save("logfile.log",robot.tosave);
shutdown;
};

function robot.dig(){
robot.tosave=robot.tosave + " NEW:"
+ time() + " dig";
waituntil(robot.ex==0);
```

```
robot.ex=1;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();
robot.actionF=5;
headPan.val=0 smooth:500ms &
neck.val=-78 smooth:888ms &
headTilt.val=10 smooth:500ms &
if(speaker.playing!=1)speaker.play("
sniff.wav"),
ledHC.val=0;
legRF1.val=-6 smooth:688ms &
legRF2.val=-9 smooth:688ms &
legRF3.val=30 smooth:688ms &
legRH1.val=-6 smooth:688ms &
legRH2.val=-5 smooth:688ms &
legRH3.val=30 smooth:688ms &
legLF1.val=-6 smooth:688ms &
legLF2.val=-9 smooth:688ms &
legLF3.val=30 smooth:688ms &
legLH1.val=-6 smooth:688ms &
legLH2.val=10 smooth:688ms &
legLH3.val=30 smooth:688ms;
legRF3.val=40 smooth:288ms &
legLF3.val=40 smooth:288ms ;
legLF3.val=20 smooth:288ms &
legRF3.val=20 smooth:288ms ;
if(speaker.playing!=1)speaker.play("
sniff.wav"),
//leg1
legLF1.val=-20 smooth:288ms &
legLF3.val=70 smooth:288ms &
legLF2.val=-9 smooth:288ms;
legLF1.val=12 smooth:288ms &
legLF3.val=30 smooth:288ms;
legLF1.val=-20 smooth:388ms &
legLF3.val=50 smooth:288ms &
headTilt.val=-10 smooth:300ms;
mouth.val=-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
legLF1.val=-20 smooth:288ms &
legLF3.val=70 smooth:288ms &
legLF2.val=-9 smooth:288ms;
legLF1.val=12 smooth:288ms &
legLF3.val=30 smooth:288ms &
headTilt.val=0 smooth:300ms;
legLF1.val=-20 smooth:388ms &
legLF3.val=50 smooth:288ms &
headTilt.val=-10 smooth:300ms;
legLF1.val=-20 smooth:288ms &
legLF3.val=70 smooth:288ms &
legLF2.val=-9 smooth:288ms;
legLF1.val=12 smooth:288ms &
legLF3.val=30 smooth:288ms;
legLF1.val=-20 smooth:388ms &
legLF3.val=50 smooth:288ms &
headTilt.val=0 smooth:300ms;
legLF1.val=-20 smooth:288ms &
legLF3.val=70 smooth:288ms &
legLF2.val=-9 smooth:288ms;
mouth.val=-35 time:233ms &
if(speaker.playing!=1)speaker.play("
bark.wav");
mouth.val=-6 time:244ms &
legLF1.val=12 smooth:288ms &
legLF3.val=30 smooth:288ms;
legLF1.val=-20 smooth:388ms &
legLF3.val=50 smooth:288ms;
headTilt.val=0 smooth:100ms &
neck.val=-20 smooth:400ms &
legRF1.val=-10 smooth:488ms &
legRF2.val=0 smooth:100ms &
legRF3.val=40 smooth:488ms &
legRH1.val=-20 smooth:488ms &
legRH3.val=55 smooth:488ms &
legLF1.val=-10 smooth:488ms &
legLF2.val=0 smooth:100ms &
legLF3.val=40 smooth:488ms &
legLH1.val=-20 smooth:488ms &
legLH3.val=55 smooth:488ms ;
legRF1.val=-6 smooth:588ms &
legRF2.val=0 smooth:588ms &
legRF3.val=25 smooth:588ms &
legRH1.val=-6 smooth:588ms &
legRH2.val=0 smooth:588ms &
legRH3.val=25 smooth:588ms &
legLF1.val=-6 smooth:588ms &
legLF2.val=0 smooth:588ms &
legLF3.val=25 smooth:588ms &
legLH1.val=-6 smooth:588ms &
legLH2.val=0 smooth:588ms &
legLH3.val=25 smooth:588ms ;

legRF3.val=40 smooth:288ms &
legLF3.val=40 smooth:288ms ;

legLF3.val=20 smooth:288ms &
legRF3.val=20 smooth:288ms ;

legLH3.val=40 smooth:288ms&
legRH3.val=40 smooth:288ms ;

legRH3.val=20 smooth:288ms &
legLH3.val=20 smooth:288ms ;
legRF3.val=35
smooth:300ms;legRF3.val=20
smooth:300ms; legLF3.val=35
smooth:300ms;legLF3.val=20
smooth:300ms;
robot.ex=0;
robot.LactionF=5;
robot.actionF=0;
};


function robot.sfront(){
robot.tosave=robot.tosave + " NEW:"
+ time() + " sfront";
waituntil(robot.ex==0);
robot.ex=1;
if(robot.actionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
}
else
robot.StandUp();
echo("start: " + time()/1000);
robot.actionF=6;
headTilt.val=44 smooth:500ms &
headPan.val=0 smooth:666ms &
neck.val=-65 smooth:666ms;
earR.val=1,
earL.val=1,
ledF1.val=true;
ledF2.val=true;
ledF3.val=true;
ledF4.val=true;
ledF5.val=true;
ledF6.val=true;
ledF7.val=true;
ledF8.val=true;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=true;
ledF13.val=false;
ledF14.val=false;
ledHC.val=0;
wait(400ms);
if(speaker.playing!=1)speaker.play("
sniff.wav"),
earR.val=0 &
earL.val=0 &

headTilt.val=32 smooth:100ms,
ledF1.val=false;
ledF2.val=false;
ledF3.val=true;
ledF4.val=true;
ledF5.val=false;
ledF6.val=false;
ledF7.val=false;
ledF8.val=false;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=false;
ledF13.val=false;
ledF14.val=false;

wait(400ms);
earR.val=1 &
earL.val=1 &

headTilt.val=44 smooth:100ms,
ledF1.val=true;
ledF2.val=true;
ledF3.val=true;
ledF4.val=true;
ledF5.val=true;
ledF6.val=true;
ledF7.val=true;
ledF8.val=true;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=true;
ledF13.val=false;
ledF14.val=false;

wait(400ms);
if(speaker.playing!=1)speaker.play("
sniff.wav"),
earR.val=0 &
earL.val=0 &

headTilt.val=32 smooth:100ms,
ledF1.val=false;
ledF2.val=false;
ledF3.val=true;
```

```
ledF4.val=true;
ledF5.val=false;
ledF6.val=false;
ledF7.val=false;
ledF8.val=false;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=false;
ledF13.val=false;
ledF14.val=false;

wait(400ms);
earR.val=1 &
earL.val=1 &

headTilt.val=44 smooth:100ms,
ledF1.val=true;
ledF2.val=true;
ledF3.val=true;
ledF4.val=true;
ledF5.val=true;
ledF6.val=true;
ledF7.val=true;
ledF8.val=true;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=true;
ledF13.val=false;
ledF14.val=false;

wait(400ms);
earR.val=0 &
earL.val=0 &

headTilt.val=32 smooth:100ms,
ledF1.val=false;
ledF2.val=false;
ledF3.val=true;
ledF4.val=true;
ledF5.val=false;
ledF6.val=false;
ledF7.val=false;
ledF8.val=false;
ledF9.val=false;
ledF10.val=false;
ledF11.val=false;
ledF12.val=false;
ledF13.val=false;
ledF14.val=false;

headTilt.val=44 smooth:100ms;
neck.val=-20 smooth:400ms &
headTilt.val=14 smooth:400ms;
robot.ex=0;
robot.LactionF=6;
robot.actionF=0;
echo("End: " + time()/1000);
};


function robot.sad()
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " sad";
waituntil(robot.ex==0);
robot.ex=1;
if(robot.LactionF==2){
legRF1.val=-6 time:1s &
legRF2.val=2 time:1s &
legRF3.val=28 time:1s &
legRH1.val=-6 time:1s &
legRH2.val=2 time:1s &
legRH3.val=28 time:1s &
legLF1.val=-6 time:1s &
legLF2.val=2 time:1s &
legLF3.val=28 time:1s &
legLH1.val=-6 time:1s &
legLH2.val=2 time:1s &
legLH3.val=28 time:1s;
};
echo("start: " + time()/1000);
robot.actionF=7;
modeG.val=0;
modeR.val=1;
modeB.val=0;

ledF1.val=0;
ledF2.val=0;
ledF3.val=1;
ledF4.val=1;
ledF5.val=0;
ledF6.val=0;
ledF7.val=0;
ledF8.val=0;
ledF9.val=0;
ledF10.val=0;
ledF11.val=0;
ledF12.val=0;
ledF13.val=0;
ledF14.val=0;
robot.StandUp();
tailTilt.val=63 smooth:1s &
timeout(15s) tailPan.val=-10 sin:4s
ampli:50,

earL.val=0 & earR.val=0;
mouth.val=-3 &
speaker.play("pupwhimper.wav") &
headTilt.val=10 smooth:2s &
headPan.val=0 smooth:1s &
neck.val=-79 smooth:1s;
headTilt.val=40 smooth:1s;
robot.ex=0;
robot.LactionF=7;
echo("End: " + time()/1000);
robot.actionF=0;
};

function robot.fwalk() {
legRF1.val=-6 smooth:688ms &
legRF2.val=0 smooth:688ms &
legRF3.val=30 smooth:688ms &

legRH1.val=-6 smooth:688ms &
legRH2.val=0 smooth:688ms &
legRH3.val=30 smooth:688ms &

legLF1.val=-6 smooth:688ms &
legLF2.val=0 smooth:688ms &
legLF3.val=30 smooth:688ms &

legLH1.val=-6 smooth:688ms &
legLH2.val=0 smooth:688ms &
legLH3.val=30 smooth:688ms ;


};

function robot.bark()
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " bark";
var a;
waituntil(robot.ex==0);
robot.ex=1;
robot.actionF=14;
a=random(4);
mouth.val=-35 time:333ms &
if(a==0)if(speaker.playing!=1)speake
r.play("att.wav");
if(a==1)if(speaker.playing!=1)speake
r.play("bark.wav");
if(a==2)if(speaker.playing!=1)speake
r.play("bark2.wav");
if(a==3)if(speaker.playing!=1)speake
r.play("happy.wav");
mouth.val=-6 time:244ms;
wait(2s);
robot.ex=0;
robot.actionF=0;
};

function robot.ball()
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " ball";
waituntil(robot.ex==0);
robot.ex=1;
robot.StandUp();
robot.actionF=15;
timeout(20s) unfreeze fotis;
freeze fotis;
ledF14.val=0;
robot.fwalk() & headPan.val=0
smooth:1s & headTilt.val=0
smooth:1s;

robot.ex=0;
robot.actionF=0;
robot.LactionF=15;
};

function robot.fwd()
{
robot.tosave=robot.tosave + " NEW:"
+ time() + " fwd";
waituntil(robot.ex==0);
robot.ex=1;
robot.actionF=9;
echo("start: " + time()/1000);
robot.swalk(1);
robot.fwalk();
robot.ex=0;
robot.actionF=0;
robot.LactionF=9;
echo("End: " + time()/1000);
};
function robot.bwd()

{
robot.tosave=robot.tosave + " NEW:"
+ time() + " bwd";
waituntil(robot.ex==0);
robot.ex=1;
echo("start: " + time()/1000);
robot.actionF=10;
robot.swalk(-1);
robot.fwalk();
robot.ex=0;
robot.actionF=0;
robot.LactionF=10;
echo("End: " + time()/1000);
};
function robot.rot()
{
waituntil(robot.ex==0);
robot.tosave=robot.tosave + " NEW:"
+ time() + " rotate";
robot.ex=1;
robot.actionF=11;
robot.sturn(5);
robot.sit();
robot.StandUp();
```

```
robot.ex=0;
robot.actionF=0;
robot.LactionF=11;
};
function robot.layd()
{
waituntil(robot.ex==0);
robot.tosave=robot.tosave + " NEW:"
+ time() + " layd";
robot.ex=1;
echo("start: " + time()/1000);
robot.actionF=16;
robot.LayDown();
robot.ex=0;
robot.actionF=0;
robot.LactionF=16;
echo("End: " + time()/1000);
};
function robot.sitd()
{
waituntil(robot.ex==0);
robot.tosave=robot.tosave + " NEW:"
+ time() + " sitd";
robot.ex=1;
echo("start: " + time()/1000);
robot.actionF=12;
robot.SitDown();
robot.ex=0;
robot.actionF=0;
robot.LactionF=12;
echo("End: " + time()/1000);
};
function robot.standu()
{
waituntil(robot.ex==0);
robot.tosave=robot.tosave + " NEW:"
+ time() + " stand";
robot.ex=1;
echo("start: " + time()/1000);
robot.actionF=13;
robot.StandUp();
robot.ex=0;
robot.actionF=0;
robot.LactionF=13;
echo("End: " + time()/1000);
};

fotis:
{
        whenever   (ball.visible   ~
70ms){
        ledF14.val=true &
        ledHC.val=false &
        modeR.val=false;
        if(neck.val<-
15)neck.val=-8 smooth:800ms,
        robot.lastvalPan=headPan
.val &
        robot.lastvalTilt=headTilt.
val;
        headPan.val                =
headPan.val + ball.a * camera.xfov *
ball.x &
        if(headTilt.val<40){
                headTilt.val   =
headTilt.val + ball.a * camera.yfov *

        ball.y;}
        else
                {
                headTilt.val   =
headTilt.val + ball.a * camera.yfov *

        ball.y;
        neck.val=neck.val  +ball.a
* camera.yfov * ball.y;
        };
        if((headPan.val>65)    &&
(robot.intransit==0)           &&
(robot.turning==0)      &&
(ball.visible==true))
        {

        robot.intransit=1;

        robot.StandUp();
                robot.fwalk2();
                var a=21;

        robot.turning=1;
        turning1:{

        headPan.val=0
smooth:1000ms,
                                for
|(var i=0;i<22;i++)
                                {

        wait(64) |

        {

        legRF1.val                 =
sturn.ctpattern[0][a] &

        legRF2.val                 =
sturn.ctpattern[1][a] &

        legRF3.val                 =
sturn.ctpattern[2][a] &

        legLF1.val                 =
sturn.ctpattern[3][a] &

        legLF2.val                 =
sturn.ctpattern[4][a] &

        legLF3.val                 =
sturn.ctpattern[5][a] &

        legRH1.val                 =
sturn.ctpattern[6][a] &

        legRH2.val                 =
sturn.ctpattern[7][a] &

        legRH3.val                 =
sturn.ctpattern[8][a] &

        legLH1.val                 =
sturn.ctpattern[9][a] &

        legLH2.val                 =
sturn.ctpattern[10][a] &

        legLH3.val                 =
sturn.ctpattern[11][a]
                                } |
                                 a--
;
                                 };
                                };
                legLF3.val=75
smooth:300ms     &     legLF2.val=6
smooth:300ms &
        legLF1.val=-20
smooth:300ms;
                legLF3.val=55
smooth:200ms;

        robot.turning=0;

        robot.intransit=0;
        },

        if((headPan.val<-65)   &&
(robot.intransit==0)           &&
(robot.turning==        0)      &&
(ball.visible==true) )
        {

        robot.intransit=1;

        robot.StandUp();
                robot.fwalk2();
                var a=0;

        robot.turning=1;
                turning2:{

        headPan.val=0
smooth:1000ms,
                for          |(var
i=0;i<22;i++)
                                {

        wait(64) |

        {

        legRF1.val                 =
sturn.ctpattern[0][a] &

        legRF2.val                 =
sturn.ctpattern[1][a] &

        legRF3.val                 =
sturn.ctpattern[2][a] &

        legLF1.val                 =
sturn.ctpattern[3][a] &

        legLF2.val                 =
sturn.ctpattern[4][a] &

        legLF3.val                 =
sturn.ctpattern[5][a] &

        legRH1.val                 =
sturn.ctpattern[6][a] &

        legRH2.val                 =
sturn.ctpattern[7][a] &

        legRH3.val                 =
sturn.ctpattern[8][a] &

        legLH1.val                 =
sturn.ctpattern[9][a] &

        legLH2.val                 =
sturn.ctpattern[10][a] &

        legLH3.val                 =
sturn.ctpattern[11][a]
                                } |
                                a++
;
                                };
                                };
                legLF3.val=75
smooth:300ms     &     legLF2.val=6
```

```
smooth:300ms &
          legLF1.val=-20
smooth:300ms;
                    legLF3.val=55
smooth:200ms;


          robot.turning=0;

          robot.intransit=0;
          },

          if((ball.ratio<0.035)    &&
(ball.y>-0.15) && (ball.x>-0.01) &&
          (ball.x<0.01)              &&
(robot.intransit==0))
          {

          robot.intransit=1;

          walking1:robot.swalk(1);
                    robot.fwalk();

          robot.intransit=0;
          },

          if((distanceNear.val<10)
&& (ball.y>0) && (ball.x>-0.2) &&
          (ball.x<0.2)               &&
(robot.intransit==0)  &&  (neck.val>-
50 ||     headTilt.val>10))
          {

          robot.StandUp();

          robot.intransit=1;
                    robot.swalk(-
1);

          walking2:robot.fwalk();

          robot.intransit=0;
          };


          },

at (!ball.visible ~ 70ms)
search: {

          ledF14.val=false;


          if(robot.lastvalPan<headP
an.val)
                    {

          headPan.val           =    60
smooth:700ms;

          headPan.val            =    0
smooth:1200ms;
                    }
                    &

          if(robot.lastvalTilt<headT
ilt.val)
                    {

          headTilt.val=37
smooth:700ms;

          headTilt.val=14
smooth:1200ms;
                    }
```

```
                        else
                        {
                        if(robot.lastvalTilt>headTilt.val)
                        {
                                    headTilt.val=-10 smooth:700ms;
                                    headTilt.val=14 smooth:1200ms;
            } &
                        if(robot.lastvalPan>headPan.val)
                        {
                                    headPan.val=-60 smooth:700ms;
                                    headPan.val=0 smooth:1200ms;
                        };};    };


at (!ball.visible ~ 2500ms){
headPan.val=0 smooth:1s &
headTilt.val=16 smooth:1s &
neck.val=-10 smooth:666ms;
};

at (!ball.visible ~ 6000ms){
search2: {
neck.val=-10 smooth:1s;
       { headPan.val'n  = 0.5 smooth:1s &
         headTilt.val'n = 1 smooth:1s } |
       { headPan.val'n  = 0.5 sin:10s ampli:0.5 &
         headTilt.val'n = 0.5 cos:10s ampli:0.5 }
      };
ledF14.val=false &
ledHC.val=true &
modeR.val=true;

};

at (ball.visible){

stop search & stop search2;
ledHC.val=false &
modeR.val=false;
};
function robot.fwalk2() {
legRF1.val=-10 smooth:688ms &
legRF3.val=40 smooth:688ms &
legRH1.val=-30 smooth:688ms &
legRH3.val=70 smooth:688ms &
legLF1.val=-10 smooth:688ms &
legLF3.val=40 smooth:688ms &
legLH1.val=-30 smooth:688ms &
legLH3.val=70 smooth:688ms ;
};
```

The robot file robot.u can be found under the folder Experiment3

Appendix V

Three Layer architecture

This research has been partially funded by the European Commission FP7 funded project LIREC in which all of the collaborative work have to comply with a standard predefined architecture. For that reason we converted the AIBOcom system into the proposed LIREC 3-Layer architecture (Figure 70).

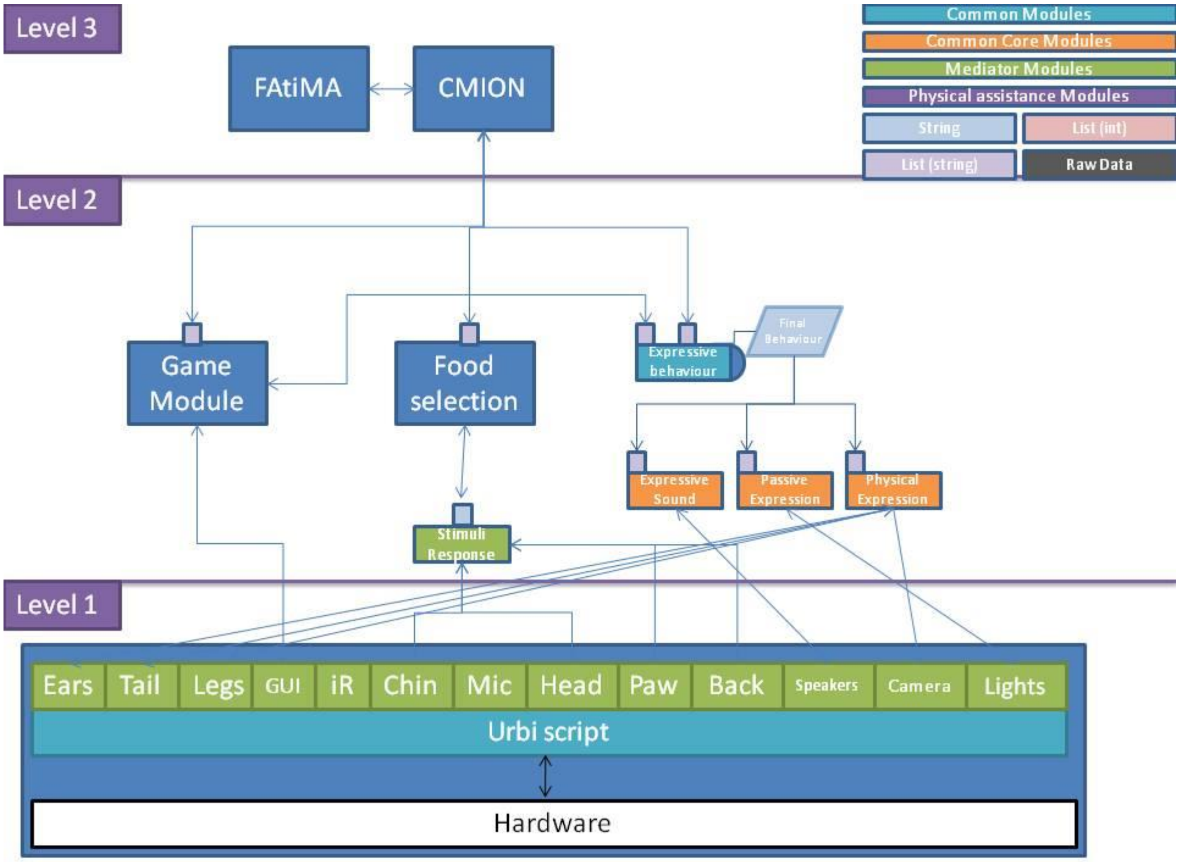
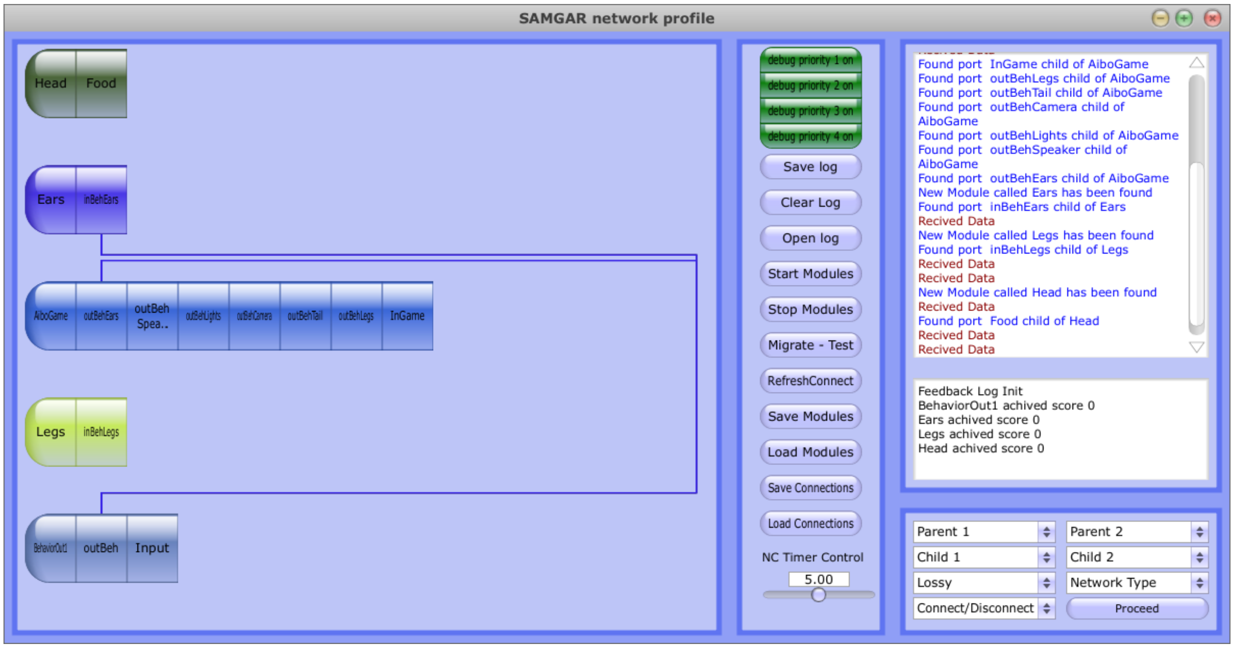


Figure 70: AIBOcom 3-Layer Architecture Diagram (Based on the LIREC 3-Layer architecture, www.lirec.eu)

The LIREC architecture is divided into 3 layers, the top layer is the companion “mind”, the middle layer which abstracts physical sensors and actuators to logical ones and passes model update information to Level 3 (top) and accepts goal-directed constraints on competences from Level 3 (platform independent). Lastly the bottom layer where the robotic modules sit and handle physical sensors and actuators for each platform (platform dependent). In order to set up and control the connections between the multiple modules and across the layers, a YARP (Metta, Fitzpatrick, & Natale, 2006) server network has been used along with SAMGAR (Du Casse, Koay, Ho, & Dautenhahn, 2009) graphical interface (Figure 71).



```
Found port  InGame child of AiboGame
Found port  outBehLegs child of AiboGame
Found port  outBehTail child of AiboGame
Found port  outBehCamera child of
AiboGame
Found port  outBehLights child of AiboGame
Found port  outBehSpeaker child of
AiboGame
Found port  outBehEars child of AiboGame
New Module called Ears has been found
Found port  inBehEars child of Ears
Recived Data
New Module called Legs has been found
Found port  inBehLegs child of Legs
Recived Data
Recived Data
New Module called Head has been found
Recived Data
Found port  Food child of Head
Recived Data
Recived Data
```

```
Feedback Log Init
BehaviorOut1 achived score 0
Ears achived score 0
Legs achived score 0
Head achived score 0
```

Figure 71: Samgar interface with modules

The companion mind (Level 3) maintains the high level memory, carries out cognitive appraisal, manages goals, generates plans and monitors plan outcomes (Ho, Dautenhahn, Lim, & Du Casse, 2010). For the LIREC project we decided to use the FAtiMA mind which complies with the proposed 3-layer architecture (Dias & Paiva, 2011). Since the 3-Layer architecture is open oriented, any mind could be connected with the system as long as it complies with the LIREC architecture. The mind is able to “migrate” from one robot to another based on tasks that the companion performs for the user. For example, in the Pioneer platform the companion cannot perform video conference and social mediator tasks, where the AIBO robot on the other hand can – thus the companion mind migrates from Pioneer to

AIBO. LIREC project defines that only one robot can be active at a particular time, therefore once the migration procedure starts, the source platform performs a sleeping behaviour and goes to standby mode while the destination platform wakes up. Allowing the mind to migrate from platform to platform based on task requirements, we can increase robot's flexibility to use the appropriate hardware while at the same time ignoring the low level complexity of the destination platform. Every system that is designed to work with the migration process complies with the LIREC 3-layer architecture.

Level 2 modules

The Level 2 architecture diagram for the AIBOcom social mediator implementation consists of the Stimuli, Game and Behaviour expression modules. These three modules are being controlled and connected directly to the FAtiMA mind (Level 3). Furthermore, as it can be seen in Figure 70, each Level 2 module is responsible for controlling and monitoring the lower level components (Level 1). The Stimuli module is responsible of converting the incoming signals from the Head module into understandable commands for FaTiMA. Its goal is to maintain the connection between them and filter unwanted information. For the LIREC demo scenario, we used this module to allow the user to select his food preference by using the AIBO robot as a communication device for delivering the choice. In order to retrieve the selection, AIBO performs a specific food selection behaviour in front of the food menu requesting from the user to select their preference by using a pink ball (Figure 72) while the AIBO's camera (on the "nose") tracks it.

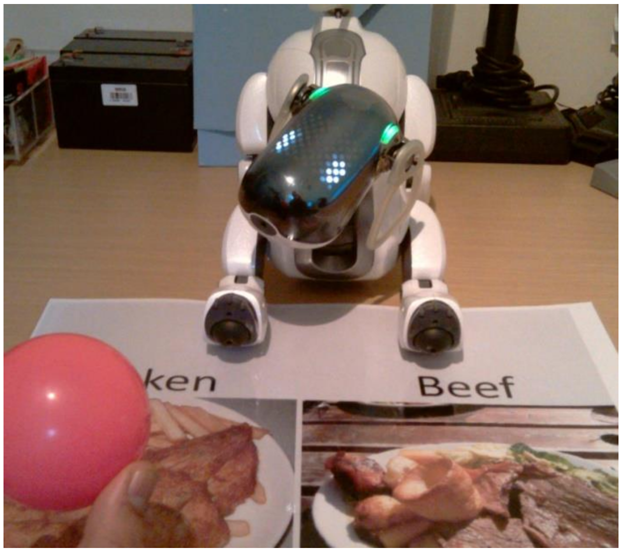


Figure 72: Food selecting behaviour

The Game module, handles the AIBOcom game functions such as starting or ending the game. It is connected with all lower level modules to synchronously provide feedback from the sensors and motion expression (e.g. ball tracking) to the actuators. Finally the behaviour module is responsible for executing expressive behaviours and sending direct commands to the corresponding lower level modules. This module has also been used on the pioneer robot in order to execute its own behaviours. It takes as an input the required behaviour from the mind and converts the input to understandable commands for the Level 1 modules. Currently the expressive behaviour module supports seven behavioural expressions, namely: waking up, sleeping, happiness, excitement, sadness, attention seeking and tiredness. Those expressions are platform dependent because each robot's embodiment differs thus the same behaviour needs to be expressed differently and has different requirements.

Level 1 Modules

This layer is responsible for controlling the hardware of each platform. Every module controls a specific part of the robot, for example legs, camera and sound module. For that reason we divided all of the AIBO functions into sub functions, controllable from multiple modules. Depending on the AIBO part, some modules have input ports for controlling an actuator and some other an output for delivering the sensory information to Level 2.

For the robot house LIREC scenario we developed the following Level 1 modules:
Ears (Output)
Legs (Output)
Lights (Output)
Speaker (Output)
Tail (Output)
Back Sensor (Input)
Head Sensor (Input)
Infrared (Input)
Paw (Input)
Camera (Head) (Output)
Chin (Output - Input)

We have developed and thoroughly tested individual modules as far as the complete 3-layer system is concerned on many real demonstrations taking place in the robot house, with great success. The system has proven its stability and modularity since it can keep on working even when several modules crash or lose their connections. In such an unfortunate event, the system will continue to function with the remaining connected modules. The 3-layer architecture will allow us and the other researchers to use any part of this code into their project without the need of further modifications. By using this architecture, other researchers will be able to develop their own platforms and use different robots without worrying about the rest of the system modules. For example if a researcher wishes to investigate the interactions between two users but using PLEO robots as social mediators, then he will have to develop a different game interface and the low level modules for the specific robot. He will then connect the new modules with our level 2 by using the 3-layer architecture without re-modelling the behaviours and the rest of the level 2 modules.