Sustaining interaction dynamics and engagement in dyadic child-robot interaction kinesics: Lessons learnt from an exploratory study*

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***Abstract*— Motivated by questions of interaction design for Human-Robot Interaction (HRI), an exploratory initial study was carried out with children and a robotic "pet" in order to improve understanding the design space for interaction with an autonomous robot. Interactions were very unstructured in a relaxing and familiar environment. The scope of the study was quite broad in order to cover a wide range of possibly relevant types of interactions. The study of the resulting interaction dynamics – with rich and with poor contextual cues – identifies key factors for interaction design and suggests some guidelines for initiating, maintaining, and regulating ongoing interaction. In particular, non-directed and directional feedback, turn-taking rhythms, and the interactional kinesics of human-robot dyads are discussed dimensions for HRI design. This is hoped to enable future studies to specifically address in more depth the issues raised in this paper.**

***Index Terms*— social robotics, human-robot kinesics, dimensions of human-robot interaction design, regulating interaction**

I. Introduction

Human-robot interaction (HRI) presents challenges related to, but distinct from, those of human-computer interaction (HCI) and the design of non-autonomous artifacts. Interaction with a physical, autonomous entity which takes up space, has mass, and initiates self-propelled movement in a space shared with humans requires particular care on the part of designers. Solutions to HRI problems may benefit from HCI and psychological insights, but are likely to require distinctive solutions.

In HCI, it has been established that in certain ways people tend to treat computers as they treat other people [30]. With technology that adheres to human social expectations, it is expected that people will find interactions enjoyable, feel empowered and competent [30]. For a given application, levels of autonomy and anthropomorphism need to be carefully designed (cf. [34], [14], [21]).

The RobotCub project develops a robot of approximately the size and shape of a 2-year old child. Within the project, the University of Hertfordshire team studies interaction dynamics between the robot and the social environment. Since a suitable humanoid robot is under development, we are using the AIBO robot as a starting point of our investigations into mapping the interaction space in order to learn about naturally occurring human-robot interactions. The AIBO was chosen since it is a commercially available, affordable robot with numerous degrees of freedom and a variety of interaction modalities. Moreover, it has been specifically designed for use as a toy by adults and children. Its robustness and interaction abilities make it well suited for an exploratory study involving children. Lessons learnt from this work are hoped to generalize to other robots, and specifically inform the design of interactional skills for the child-like robot which is in development. Since children usually show much more playful behaviour towards a robot than adults, we chose 9-13 year old children as our subject group. In this age range we can expect children to still be very playful, and not as restrained as adults. However, by this stage they already possess advanced cognitive abilities and interactional competencies.

The robot's behaviours in our study were triggered by the experimenter who (taking the role of the robot) interpreted the interactions and the meaning of the children's behaviour, and then selected the appropriated responses for the robot. The study thus simulated a situation where a future robot would be able to make such decisions autonomously, rather than investigating how people respond to existing robotic systems.

The purpose of the present study was not to carry out an experimental user study which would require, among other things, much larger sample sizes, control groups, within- or between-subjects design, and statistical evaluation of the results. Our exploration into the design space of child-robot interactions, from the perspective of a future robot with advanced perceptual abilities, meant that we were not interested e.g. in frequencies of behaviour or comparisons among experimental conditions (e.g. rich context/poor context). Also, in this initial study, we were not analyzing the influence of different robot appearances on subjects, as done e.g. in our previous work [31]. Instead, in this *robot-centered perspective*, our aim is to develop robots that might successfully engage and sustain interactions

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with people. This perspective is different from a human-centered perspective investigating how subjects respond to currently available autonomous robots, as shown in work by psychologists (e.g. [17]), as well as roboticists (e.g. [18]).

A useful concept is that of *design space*, encompassing the possibilities along various dimensions for particular types of artifacts. Design spaces help a designer to understand and assess the possibilities, requirements, and dimensions of design in particular application *niches*. Design spaces for cognitive architectures [36] and for social robotic agents [11] have been introduced. Our goal here is to study aspects of the niches and design space for human-robot interaction.

Note, in this paper we follow Ogden et al.'s definition of interaction as *a reciprocal activity in which the actions of each agent influence the actions of the other agents engaged in the same interaction, resulting in a mutually constructed pattern of complimentary behaviour* [29].

A. Social Robots and Believable Agents

Endowing robots with social behaviour so that they can interact with each other and with humans and other agents has been a fundamental research direction since the time of W. Grey Walter's early minimally social robots Elsie and Elmer in late 1940s [39], has attracted growing interest since the early 1990s [8], and has recently become a mainstream robotics area [15].

Robotics researchers have been working toward the design of more believable or enjoyable robotic behaviours that may exploit natural human tendencies to anthropomorphize robots or be favorably disposed to agents of cute infant-like appearance (e.g. large head and eyes of the *Kindchenschema*, such as in the robots Kismet [4], [3] and Infanoid [20], where this is used to elicit and encourage "'care-taker"-like behaviour in humans).

Agents and robots whose behaviour and interaction make narrative sense (see [12]) to humans as social beings are called *believable* [2], [9]. Moreover, social and narrative intelligence may lie at the core of what we understand as human intelligence [6], [12], so developing social skills in robots that 'grow up' – i.e. have a personal ontogeny, developing in the context of social interaction, suggests an approach for achieving human-like intelligence in artificial agents [13], [33], [26].

B. Human-Human Interactions

Achieving 'naturalness' in human-robot interaction by modeling it on human-human interaction has been a goal of many researchers (e.g. [18]), although it is not quite clear what degree of similarity to human appearance and behaviour is required in order not to fall in the 'uncanny valley' [11], which refers to situations when people feel uncomfortable with robots that are too human-like, but still not identical in behaviour and appearance to humans.

Evidence from developmental psychology suggests that much of human intelligence and the development of primary intersubjectivity as well as communication and language may develop on the scaffolding of *communicative imitation*, *turn-taking dynamics*, and *contingency* starting from early mother-infant interactions and preverbal communication [37], [1], [38], [5], [23], [24], and not surprisingly there is increasing interest in some of these mechanisms in robot design [10], [3], [25].

On the other hand, human-human interaction involves subtle adjustments and synchronizations of timing of movement of which we are often unaware [19], [7]. *Kinesics* is *the study of the role and timing of nonverbal behaviour, including body movements, in communicative and interactional dynamics.* Effector movements (hands, limbs, nodding, prosodic aspects of speech - such as coordinated rhythmic timing of vowels in first syllables of words, gaze direction change, etc.) and mirroring are subtly used to regulate human interaction: entering or breaking a rhythm serves in human-human dyads, and also groups, to regulate interactions, such as turn-taking, topic shift, entering or leaving a conversation [19]. Temporal scales of some of this behavioural coordination can be on the order of a few tens of milliseconds. Significant cultural differences in such timing (at this and other scales) and mismatches between cultures can lead to significant difficulties for human interaction [16]. This suggests that interacting with robots with no sense of human time and timing is also likely to be unnatural or uncomfortable. Traditionally kinesics has focused on human-human interaction in anthropological and psychological studies, but we propose here a more general view of kinesics motivated by the fact that interactive robots present us with the need to study and understand *human-robot kinesics*. Robot-human temporal interaction kinesics will eventually need to be studied deeply in order to put this dimension within the purview of HRI designers.

II. Exploring the Space of Robot-Child Interaction

In the context of the above issues, we formulated the following research questions in order to better understand the space of possible human-robot interaction designs, focusing on interactions with children:

- In what ways do children discover how to operate/interact with a new robotic toy?
- How can we sustain interaction levels once the novelty of the toy wears off?
- Does providing an environmental set-up which serves as a richer context help promote more interaction?
- Can we classify specific interaction dynamics which engage the participants most and which are most likely to encourage a participant to continue the interaction beyond the initial curiosity/discovery period?

When analysing the interaction dynamics we can identify two situations:

• The human takes the initiative - the robot is passive and only responding to human actions. Here, we are concerned with the robot's behaviours and how they are perceived by the human whose actions will determine how the robot responds.

Fig. 1. The Aibo robot

• The robot takes the initiative - this covers the dynamics of the robot's actions that promote interactions. For example:
-Walking towards the person or away from the person,
-Making sounds that can be perceived as meaningful in the context of the interaction,
-The repetitional response of the robot to specific human action that helps to create a rhythmic interaction

We focused on identifying factors in child-robot interaction kinesics that can contribute to interaction design for robots meant to engage and sustain engagements with human subjects. Based on these results that derived from a qualitative analysis of the video material collected, future, more specific and quantitative experimental studies can investigate these factors in more depth and provide experimental data for detailed hypothesis testing.

III. The Trials

The trials were conducted in a play room set-up at a private home, which was familiar to the children (all of whom were from the same neighborhood), to allow the children to interact with the robot in a relaxed atmosphere, in an environment in which it is natural for them to play. Six trials were carried out with one child each, two with a very poor contextual setting and four which provided a rich contextual setting appropriate to having a dog pet. Each child was exposed to only one condition.

A. The Robot and Context

The robot used in these trials is the above-mentioned Aibo- a 'dog' robot made by Sony. The robot was used in two set-ups:
1) The robot was presented to the participant without any environmental contextual objects- only with an additional pink ball that originally came from the manufacturer together with the robot. Thus, in this setup the context provided is very poor.
2) The robot was presented to the subject in an environment that in addition to the pink ball, included objects that are suitable for providing a richer context of having a dog pet, such as kennel, dog's chewing bones, and a bowl (Fig. 2).

The robot's actions were controlled remotely by the experimenter who executed the movements, sounds and simple behaviours in response to and in order to encourage interaction with the participants (Wizard-of-Oz method).

Fig. 2. The robot with the additional contextual objects

In addition, the robot had a few simple autonomous behaviours triggered by its touch sensors. Only one behaviour was active at a time.

B. Robot Capabilities

The robot exhibited the following actions/behaviours that were selected due to their suitability for the trials:

- Sounds: Whine, Bark, Growl, Sniff, Break-wind
- Actions: Sit, Stand, Move head left or right
- Walk (remotely controlled by the experimenter, forwards, backwards, left, right)
- Dance (involves sitting on haunches, and raising/lowering forelimbs)
- Chase Ball - Autonomous behaviour that allows the robot to follow a pink object
- Stare At Ball - Autonomous behaviour that allows the robot to follow a pink object with its head only
- Responses to Touch Buttons:
  -Back button: Lift head, open mouth and howl
  -Head buttons: Wag tail and yipper in delight
  -Chin button: Sniff

The robot's behaviours can be classified into two categories:

- Extended behaviours: Once triggered by a start key, the behaviour is exhibited until a stop key is pressed. These includes chasing the ball and staring at the ball. In the case of remotely controlled walk, walking continues as long as the start key is pressed, and stops when the key is released.
- Short duration behaviours: These behaviours are performed for a pre-set duration once the corresponding key is pressed (approx. duration in seconds): Remotely activated actions including Sit, Stand and Move head left/right (one second each), and Dance (6 seconds). Remotely activated sounds were Whine and Break Wind (one second each), Bark (three yips, 1.5 sec. total duration for a bark action), Growl (3 seconds), and Sniff (2 seconds). Durations for touch button responses were as follows: 4 seconds (Button on Back), 1.5 seconds (Button on Head), 2 seconds (Button under Chin).

C. Trials set-up & procedures

Six children in the age range 9-13 who never had seen the AIBO robot before participated in this preliminary study. Prior to the study, the parents were approached by the experimenter and asked to sign a consent form to allow their children to participate in the study. The consent form explained the purpose of the study addressing the robot as a 'robot artifact' and 'puppy robot', and referring to it as AIBO. The parents then discussed with their children this invitation to participate in the study. Thus, we can safely assume that all the children expected to see a robot or a robot that looked like a dog.

The trials took place in one of the homes of the children in order to provide an atmosphere that was as relaxed as possible. The children were familiar with each other and the experimenter. The room was a large open-plan room partitioned by a sofa, leaving an empty play area of approximately 2m $\times$ 2m. Trials lasted from 3:32 to 8:05 minutes (average trials duration 5:48 minutes).

The investigator was sitting in one corner operating his laptop as necessary to control the robot. Before each trial, the robot was placed at the opposite corner of the room, switched on, on standby, awaiting interactions. The investigator, unknown to the participants, was using his laptop to communicate with the robot via a wireless LAN that was set-up in the room prior to the trials. The keyboard, used to control the robot, was visually hidden from the children. None of the children indicated during the trials that they noticed the remote control of the robot. A few times, when unsure what to do, the children looked at the experimenter but they never looked at the experimenter in anticipation of the robot to react. After the trials, when the role of the experimenter was revealed to them, all children showed surprise. Since the children were very familiar with the experimenter they widely ignored him during the trials, unless the experimenter addressed them.

A stationary video camera was placed behind the investigator, capturing the play area in the room. The trials were designed for the children simply to be exposed to the robot, familiarize themselves with it (as a new toy) and find ways how to interact with it. The children entered the room one at a time with the invitation to come and play with the robot. The invitations were given as "You can play with the robot." or "You can play with the robot dog.". They were not given any information about the robot's capabilities, nor any instructions on how to operate, play or interact with it. The experimenter decided which robot behaviours to trigger with the aim of maximizing the robot's ability to engage the children and sustain the interactions.

IV. Interactional Dynamics

The children's actions during the trials can be placed in the following two categories:

- Attention seeking behaviour to initiate interactions (e.g. vocal command, throwing ball, placing bone etc)
- Attention keeping behaviour to sustain interactions (e.g. sequence of verbal commands, repetition of interaction games, etc)

Fig. 3. Limited interaction with poor contextual setting

The following are samples from various trials, representing the characteristics and dynamics of the interactions in the different scenarios.

A. Trials with poor contextual setting

These trails can be characterized by very limited interaction patterns. In one trial the child tried to wave his hand in front of the robot. When this did not work he used verbal commands similar to those used with pet dogs such as "walk" to engage the robot in the interaction. However, despite the appropriate response of the robot to these instructions, the child became very passive after the initial phase (Fig. 3) and did not try to repeat any vocal commands, nor to find any other ways of interaction (e.g. touching the robot or using the pink ball that was available). The child also remained passive to the robot's bids for interaction (when it produced various sounds).

In a trial with another child in the same setting, the child showed very similar limited ways of interaction. The child attempted to interact with the robot only by throwing the ball away from the robot and waiting for the robot to follow it. The child did not try any other way of interaction, and became passive after the initial phase. The child was also initially reluctant to use touch as a way of interaction when suggested by the investigator and did so for a brief period of time (twice for less than a second) only after repeated encouragements. Different from previous work where we detected touch via the robot's sensors [32], judgments on the children's behaviours were done based on the video material.

B. Trials with rich contextual setting

In all the trials with rich contextual setting, the children tried many different ways of encouraging interaction and sustaining it for a long period of time. The following example illustrates the various ways of interaction and the interactional dynamics which appeared in most of the trials, and highlights that *a rich contextual environment encourages the children to initiate interactions.*

In this example (see Fig. 4), the trial started where the robot was situated inside the kennel. The child took the initiative and used various methods (in this context

Fig. 4. Luring the 'dog' out of its kennel with a bone.

appropriate to a pet dog) to try to get the robot to come out of the kennel:

- Child tries barking like a dog - after hearing it bark/whine inside the kennel puts a ball in front of the robot.
- Child tries to get the robot to fetch the ball by throwing it.
- Child uses verbal commands to the robot
- Child tries to lure the Aibo out of the kennel with the bone by showing the bone and waving it in front of the Aibo's face.
- Child tries waving the bone and calling "Walkies!", "Come on - bone!"
- Child places the bone at a distance from the robot to lure it out of its kennel.

In this trial the child was not afraid of touching the robot to help it out of the kennel when it got stuck.

The interaction was sustained for a long period of time, with the robot using various sounds to encourage interactions (e.g. barking, sniffing etc.) and with the child using various objects to interact with the robot (e.g. the ball for following the ball game, the bone for sniffing, etc.).

C. Rhythmic actions in repetition as a way of sustaining interactions

In several of the trials the children took the initiative and tried to attract the robot's attention by waving their hand in front of the robot's face. When the robot responded to this action they repeated this behaviour and started to lead the robot around the play area using the hand (see Fig. 5).

Similarly, when the robot initiated interaction with a sniffing sound we observed occasions where the children responded by positioning the bone in front of the robot. At times the children tried to lead the robot 'by its nose' (Fig. 6). Later children repeated this interaction on their own initiative, handing the bone to the 'dog', encouraging it to 'sniff' several times.

Fig. 5. Child leading the robot with her hand

In both these examples we can see how the child's initiative together with the appropriate response of the robot, encourages repetition of behaviour, becoming a rhythmic 'call and response', and sustaining the interaction over longer periods of time.

D. General observations

Based on the video material the researchers collectively identified relevant interaction sequences that are presented descriptively in this paper.

In all the trials, it seemed that the children projected into the interactions their knowledge and experience with real dogs, and expected the robot to have real dog skills. Examples that illustrate this are:

- They used verbal commands to initiate interactions similar to the way a person would command a real dog.
- They acted as if they thought initially that the robot can perceive and move at the speed of a real dog, evidenced by the fact that the ball was thrown quite fast for the robot to fetch. Most of the children were not inclined to touch or stroke the robot (maybe due to the unnatural metallic look and texture of the robot's surface) and none of them pressed the touch button sensors, except when explicitly

Fig. 6. Robot and child responding to each other.

prompted by the investigator. Similarly, the natural colored bone and pink ball were used by most of the children, but none of them used the pink bone (perhaps due to its unnatural color).[1]

E. Discussion

The trials showed that contextual objects of the natural (domestic) environment of a dog increased the level of interaction with the children both in providing more opportunities to initiate interaction and more ways to sustain interactions. In order to sustain the interactions the responsiveness of the robot during the interactions was shown to be important, and the response time of the robot needed to be kept very short. The robot needed to be able to pick up on many different types of attention seeking behaviours of the children, often occurring simultaneously and expressed in various modalities.

V. Lessons for Sustaining Human-Robot Interaction

We summarize some key factors identified from our exploratory study into the dimensions of human-robot interaction design:

1) **Context.** Appropriate context which suggests interactional activities to humans can serve to motivate interaction. However, providing a rich context can raise expectations on the robot's perceptual and motor abilities that the robot does not necessarily have (e.g. the ability to respond to verbal commands, fast visual tracking, the ability to carry an object).
2) **Initiating interaction.** Acoustic and visual signals (like barking, raising the head, beginning visible motor activity) can serve to attract attention.
3) **Regulating interaction.** Responding in a timely manner, moving toward an object of joint attention, and rhythmic exchange can help serve to sustain an interaction and regulate role-switching in rhythmic interactions. Conversely, moving away, not responding in a timely fashion, etc., can lead to interaction breaking off.
4) **Showing attention - feedback as expression of interactional state.**
   a) *Speed* and *timing* of a robot's response to human actions influences interaction and whether or not it is sustained.
   b) Feedback of this sort can be: *non-directional* feedback (barking, raising the head, beginning to move)
   c) Orienting Response - *directional* feedback via orientation toward the interaction partner or object which suggests interest and *attention* (or *joint attention*).
5) **Turn-taking.** Together with *novelty* (discovering new behaviours of the robot), the possibility for turn-taking interactions appears to significantly contribute to sustaining interaction.
6) **Rhythm, kinesics, body motion and timing.** Responding with appropriate timing so as to mesh with the timing of human actions encourages sustained interaction.

VI. Conclusion and Directions

We reported on results from an initial exploratory study into how a future robot can sustain interaction dynamics and engagement with people. Results from our study into mapping the design space of human-robot interaction dynamics are hoped to enable future studies to specifically address in more depth the issues raised and dimensions identified in this paper.

We have shown the strong impact of *context* and contextual cues on the regulation of interaction in human-robot dyadic interaction.

Showing attention (directional or *non-directional)* by the robot was also seen to be very important in regulating interaction. *Feedback* in human-robot interaction (HRI) can be compared in its importance to that in the design of other interactive systems and in psychology. In human-computer interaction and device design, the corresponding principle is that a system should acknowledge, in a timely fashion, with a signal perceptible to the user that it has received and is acting on input from the user (e.g. with a beep or hourglass in many HCI examples) – see for example [35], [27]. This is clearly also the case for human-robot interaction, although the types of response possible are much more varied and the physical embodiment raises particular issues of orienting, deixis, and joint attention.

[1]The pink bone was presented as an alternative to the naturally colored bone as an additional interaction tool, in the hope that the children would discover the robot's embedded tracking behaviour (for following pink objects).

The rhythm, timing of movement and turn-taking in interaction (*kinesics*) have strong influences on its regulation and naturalness in human-human interaction [19], [16], and we have seen some of their impact on sustaining interaction dynamics in this study. Robots, unlike humans, do not presently have a natural “internal clock” and do not adjust the timing of the interaction to that of a human interaction partner, but the timing of robotic interaction could be designed to adaptively help regulate interaction. Some pioneering work of Japanese researchers has recently begun to touch on issues of using adaptive entrainment in human interaction with artificial interaction partners, e.g. as an aid to walking rehabilitation [22] or as an attentional, educational and persuasive aid [28], [40]. Nevertheless, the details of this area of *robot-human interaction kinesics* are a still almost completely open — but likely very fruitful — area for human-robot interaction design.

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