Robot to Human Approaches: Preliminary Results on Comfortable Distances and Preferences

Michael L. Walters, Kheng Lee Koay, Sarah N. Woods, Dag S. Syrdal, K. Dautenhahn
Adaptive Systems Research Group, School of Computer Science
University of Hertfordshire
College Lane, Hatfield, Hertfordshire, UK, AL10 9AB.
{M.L.Walters, K.L.Koay, S.N.Woods, D.S.Syrdal, K.Dautenhahn}@herts.ac.uk

Abstract

This paper presents results from Human Robot Interaction (HRI) trials carried out at the University of Hertfordshire which examined how a robot companion must behave when fetching and carrying objects to and from human participants in a domestic 'living room' scenario. It was found that different social approach rules apply depending whether the interacting human is sitting, standing in the open, or against a wall or obstacle. The main purpose of this paper is to demonstrate the techniques for automatically annotating HRI trial videos with participant supplied comfort data. During the trial participants indicated via a Comfort Level Device (CLD) their preferences for robot approach distances. This data was correlated with distance measurements obtained from the CLD annotated video recording of the trials. The development of a post-processing technique for overlaying a structured grid on to the video recordings of the trial, allowed a continuous record of both human and robot's positions and distances during the HRI trials to be recorded. Implications and suggestions for further HRI trials and an improvement of the methodology conclude the paper.

Introduction

As domestic and office robots will have to carry out useful tasks in the same workspace as humans it is important that robots will have to respect people's social spaces and shared workspace preferences. The studies described in this paper are part of our long-term goal to investigate requirements and 'social rules' (a 'robotic etiquette') for a robot companion which is able to a) perform useful tasks in a home environment and b) behave in a manner that is acceptable and comfortable to humans (Dautenhahn, 2002). Our main research is in the area of Human-Robot Interaction (HRI), in particular with regard to socially interactive robots (Fong, Nourbakhsh and Dautenhahn, 2003). This paper presents research carried out towards the development of a Cognitive Robot Companion for use in a domestic environment as part of the work for the COGNIRON Research project (COGNIRON, 2007). We are primarily interested in the human perspective of how robots could be useful in domestic environments; in particular the roles, tasks, and social behavior that will be necessary for robots to exhibit in order to integrate into normal domestic situations (Dautenhahn et al., 2005).

In order to study human-robot relationships, we have previously run HRI trials using carefully devised test scenarios (Walters et al., 2005a; te Boekhorst et al., 2005; Woods et al., 2005), where human responses and opinions can be collected using a variety of methods. There are two main reasons why human-robot interaction trials need to be carried out with scenarios that seem 'natural' in a human-human setting:

1. Often, the behavior which is under investigation is seen as so trivial or obvious, that there is little or no previous published work available for similar human-human interaction situations. Therefore, carrying out user HRI trials is the only way to understand how robots should behave under these little researched conditions.
2. As the study of socially interactive robots is relatively new, experimenters in the field often use existing research into human-human social interactions as a starting point.

However, even where there is information about an interaction for the human-human context or scenario, it is important not to assume that robots should behave in the same way as a human in a comparable situation. Indeed, we have found that this is often not the case (Walters et al., 2005c). Therefore, any assumptions of how robots should behave which are based on similar human-human interactions should always be tested to verify how applicable they may be to human-robot interactions. Hall (1966, 1968) provided a basis for research into social and personal spaces between humans, and later work in psychology has demonstrated that social spaces substantially reflect and influence social relationships and attitudes of people. Moreover, embodied non-verbal interactions, such as approach, touch, and avoidance behaviors, are fundamental to regulating human-human social interactions (Hall, 1968). This has provided a guide for more recent research into human reactions to robots (Dario, Gugliemelli and Laschi, 2001: Severinson-Eklundh, Green and Hüettenrauch, 2004). Michalowski,

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DiSalvio and Sabonovic (2006) have used a model of social engagement, which includes human-to-robot approach distance and direction to assess human intent to interact with a robot.

Other work has generally assumed that robots are perceived as social beings and that humans will respond to a robot in a similar way, for example, as to a pet, another human, or even as to a child or infant. There is evidence to support this view in that humans do respond to certain social characteristics, features or behaviors exhibited by robots (Breazeal (2002): Kanda, Hirano and Eaton, 2002). Reeves and Nass (1998) provided evidence that even in interaction with computers people exhibit aspects of social behavior. However, a study by Friedman, Khan and Hagman (2003) has shown that while people in many ways view an Aibo^{TM} robot like a real dog, they do not treat it and view it in precisely the same way as a living dog (e.g. with regard to moral standing). Walters et al. (2006) have found that humans prefer approach distances towards robots which are comparable in some ways to those found for human-human social distances (Hall, 1996; Hall, 1998). However, many humans do not seem to mind very close approaches to the robot which in a similar human-human context would be perceived as over-familiar or threatening. Thus, it is unlikely that people will react socially to robots in exactly the same ways that they might react to other humans or other living creatures in comparable contexts (Norman, 1994; Dryer, 1999; Khan, 1998).

As domestic and office robots carry out useful tasks, they will have to move physically around in the same workspace as humans. However, it is important that robots will not just simply move around and avoid people in the same way as they would an inanimate object but they will have to respect people's social spaces and shared workspace preferences. Note, our work uses a mechanical-looking robot without any intention to make it look or behave exactly like a human.

Fetching and carrying objects is an important component of a wide range of useful tasks for a robot companion in the home, the eventual aim of these studies is to provide a set of rules and parameters that can be used to provide guidance to the designers and builders of domestic (servant) robots in the future. The overall research question addressed is therefore:

How should a robot approach a human when fetching an object to the human?

Previously, a series of exploratory and pilot Human Robot Interaction (HRI) trials were carried out with one of the main objectives of addressing the above question (Woods et al. 2006a, Dautenhahn et al. 2006, Koay et al. 2005; Walters et al. 2005b; Walters et al. 2006). In light of encouraging results from the small scale exploratory and pilot studies, a larger scale main study was instigated which investigated further aspects of how robots should approach and serve human participants in a socially acceptable way. The specific aspects relevant to those being addressed here was to investigate how a robot should approach a seated human and also, the further development of techniques and methods of using data from a hand-held Comfort Level Device (CLD). The CLD provides signals which effectively allow the user to automatically annotate trial videos directly during HRI trials runs. Other aspects of this study, previously published, include investigating the relationship between participants' personality traits and their approach preferences (Syrdal et al. 2006) and comparing results from video based HRI trials with live trial results (Woods et al. 2006). In previous publications, reporting on the pilot trials, we only considered the robot approach directions in the context of questionnaire data indicating participants' preferences (Walters et al. 2007). The current paper documents a technique for which could be used for combining questionnaire data with data obtained from participants using a Comfort Level Device (CLD) (Koay et al. 2006a, 2006b). The integration of data from different experimental measurements is hoped to deepen our understanding of the issues involved. Walters et al. (2007a) provides a detailed description of the experimental setup and the questionnaire based results on participants' approach preferences gained in the main trial. Brief summaries are given below.

Robot to Human Approach Trials

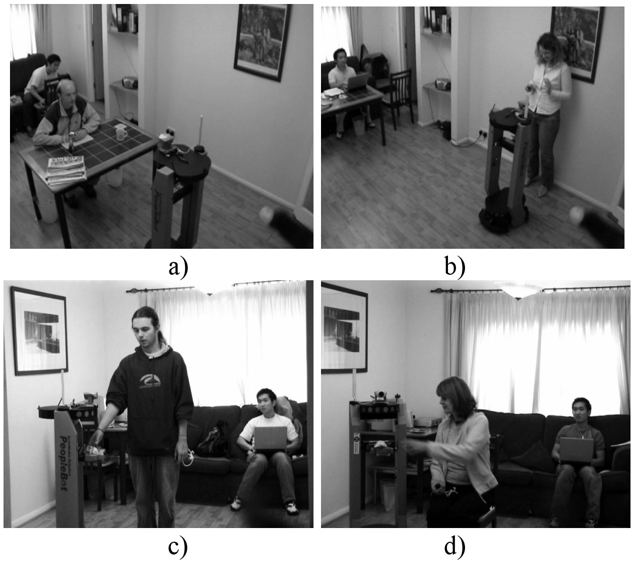
The specific aspect that the pilot studies considered was how a robot should approach a seated human. Therefore, the relevant aims of these trials were:

> *To confirm and consolidate the results previously obtained from pilot studies.*
>
> *To extend the range of human-robot interaction situations and scenarios from those studied previously.*

The trial was performed at non-University premises. In order to provide a more ecologically valid experimental environment, an apartment near to the University was rented, referred to here as the "Robot House", and the main living room furnished and used as the venue for the large scale trials. Feedback from the participants indicated that they thought the Robot House was not like a laboratory, they felt less as if they were being tested and the perception of the experimental area was more 'neutral' than a laboratory.

In total, four different scenarios were studied in the trials where a robot approached the participant who was located in the living room:

1. Seated on a chair in the middle of an open space.
2. Standing in the middle of an open space.
3. Seated at a table in the middle of an open space.
4. Standing with their back against a wall.



a) b)

c) d)

1) **Views from the Robot Approach Direction Trials. a) Seated at table, b) Standing against wall, c) Standing in middle of room, d) Seated without table.**

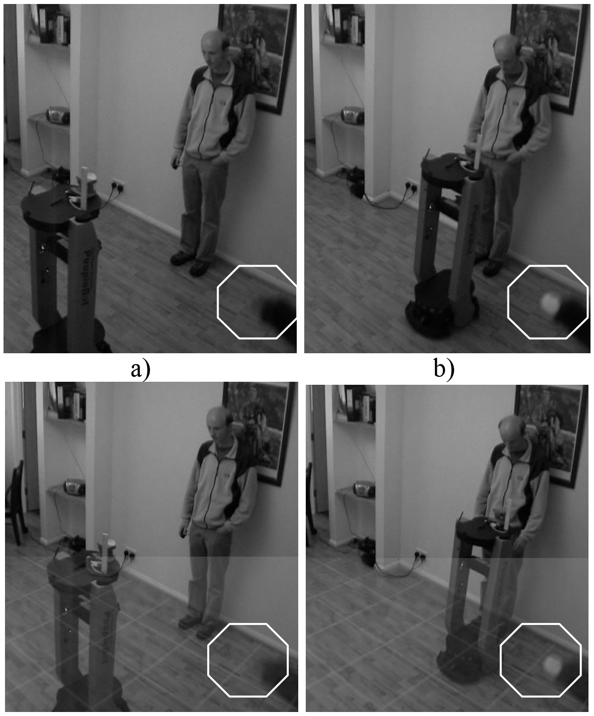
These particular interactions were chosen as they were typical approach situations which would be encountered in a wide range of fetching and carrying tasks that a domestic robot might be expected to carry out. It is hoped that once the appropriate approach behavior expected of robots is known, these actions could then be used as 'primitive' robot action components which could be sequenced appropriately into more complex task scenarios involving a robot approaching a human. The trials were performed in the living room of the Robot House. There were a total of 42 participants, who each experienced two of the scenarios from the four described above.

Summary of Experimental Setup

The studies used a commercially available PeopleBot^{TM} with standard equipment fitted, including a pan and tilt camera unit and a standard short reach lifting gripper which was adapted to form a simple tray in order to fetch and carry objects as required. During the trials, most of the furniture was arranged at one end of the room, to provide a large clear space for carrying out the HRI trials. A chair and/or table were moved to the central position as required for the trial scenarios where the participant was to be seated in the middle of the room or at the table. First, a short introduction video was shown to the participant, followed by consent forms and introductory questionnaires before the robot to human approach trials began.

Two video cameras recorded each trial; one fixed overhead wide angle camera with an overview of most of the experimental area, and a tripod mounted video camera which recorded a closer view of the participant. After the trials were complete, the floor area was laid out with adhesive tape in a 0.5m grid pattern.

2) **The Comfort Level Device**



a) b)

c) d)

3) **Clips from the HRI trial videos illustrating the use of the CLD (red light- circled) in b) and d). The video is then overlaid with a 0.5m grid in c) and d).**

Photographs were then taken from the exact viewpoint of the fixed overhead video camera. This photograph was then overlaid transparently onto the video recordings from the overhead camera, in a separate post processing operation using video editing software (see Figure 3). The process is demonstrated in Walters et al. (2007b), where some initial videos from more recent follow up trials are to be presented.

During the trials, participants were encouraged to use a small wireless signaling device when ever they felt *uncomfortable* with the proximity of robot. The device, which was developed from the latest prototype of the Comfort Level Device (CLD) (Koay et al. 2006b), consisted of a small key-fob sized transmitter with a single button which was easily pressed by the trial participant (Figure 2). The signal was received by a receiver and a small light was illuminated whenever the CLD device button was pressed. The receiver was mounted to the fixed video camera, so that the light flashes were recorded onto the corner of the video recordings of the trials (Figure 3). In this way, the video recording was automatically annotated with the participants' discomfort signals. The distance between the robot and human participants was able to be estimated (to the nearest 0.25m increment on the overlaid grid 0.5m grid) each time the CLD signal was perceived on the post processed video recording. These distance measurements form an important part of the key trial data to be considered in this paper. After each HRI approach trial a questionnaire was administered to gain the participants' categorical (5-point Likert scale) ratings of preferences regarding: the most preferred and least preferred approach directions, and the approach directions judged as most and least efficient. A summary of the main results is provided here. For full details of the statistical analysis of the questionnaire data, see Woods et al. (2006) and Walters et al. (2007).

Summary of Results from Questionnaires on Approach Preferences

The statistical analysis of the questionnaire data included a non-parametric Friedman analysis of variance by mean ranks to determine whether there were significant differences between participant comfort rating preferences for the different approach directions. The Friedman test was also used to analyze participants' ratings of the robot's task efficiency.

Seated at Table Condition

Participants rated the front left and front right approaches as the most comfortable and found the rear approaches the least comfortable. Participants had no preference for the level of task efficiency and the approach direction used by the robot.

Standing Against a Wall Condition

Participants rated the front direct approach as less comfortable compared to the front left and front right approaches. No significant differences were found between participant robot task efficiency ratings for the robot approach directions.

Seated in Middle of Room Condition

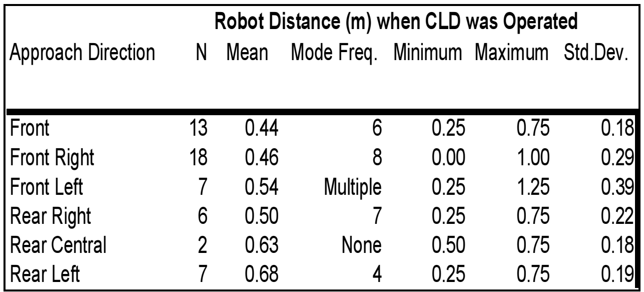
Participants rated the front left and front right approach directions as more comfortable than the rear approaches and the frontal direct approach. Participants did not display overall preferences for a more or less efficient robot approach direction.

Standing in Middle of a Room Condition

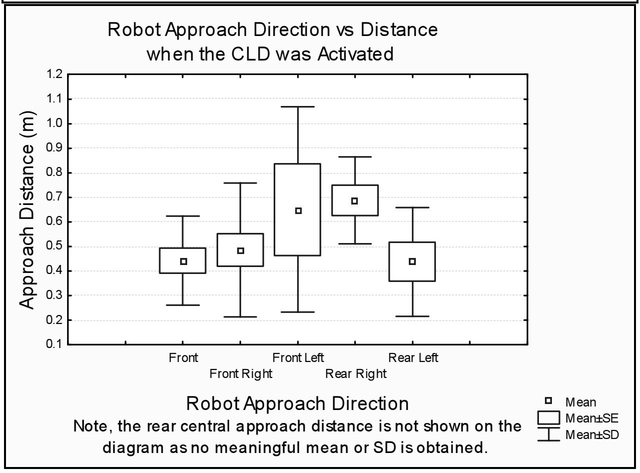
Participants clearly felt the least comfortable with the rear central approach direction and were the most comfortable with the front left and front right approaches. The rear central approach was rated by participants as being the least efficient, and the frontal approach. front right, and front left approaches were rated as the most efficient.

Results from CLD Distance Measurements

The results from the uncomfortable distance measurements were obtained and are given in the Table in Figure 4. The distances were measured from the closest part of the robot base to the human participant to the closest part of the participants' feet. The mean and Standard Deviation (SD) values for the rear central approach direction are not very informative (as N=2, df = 1), so are not shown in the included diagram. The mean distance values for the front left approach direction are also un-reliable due to the small size of the sample.



	Robot Distance (m) when CLD was Operated					
Approach Direction	N	Mean	Mode Freq.	Minimum	Maximum	Std.Dev.
Front	13	0.44	6	0.25	0.75	0.18
Front Right	18	0.46	8	0.00	1.00	0.29
Front Left	7	0.54	Multiple	0.25	1.25	0.39
Rear Right	6	0.50	7	0.25	0.75	0.22
Rear Central	2	0.63	None	0.50	0.75	0.18
Rear Left	7	0.68	4	0.25	0.75	0.19



Note, the rear central approach distance is not shown on the diagram as no meaningful mean or SD is obtained.

4) Measurements Obtained using the CLD Signals in conjunction with the Video Grid Overlay

Unfortunately, the number of samples was much smaller than expected and there were not enough valid results to perform a full range of statistical tests taking into account the four approach situation conditions. As can be seen in the Table in Figure 4, most participants only used the CLD for one or two approaches at best and instead of a possible maximum of 285 distance measures, we only obtained 42 measurements.

Robot Distance (m) When CLD Operated

Approach Conds.	Front	(N)	Fr. Right	(N)	Fr. Left	(N)	R. Right	(N)	R. Left	(N)
Seated Middle	0.38	4	0.43	10	0.75	1	0.63	2	0.75	3
Standing Wall		0	0.44	4	0.25	3				
Seated Table	0.58	3	0.75	1	0.75	1	0.44	4	0.63	4
Standing Middle	0.42	6	0.50	3	0.75	2		0		0
All Groups	0.44	13	0.46	18	0.54	7	0.50	6	0.68	7

5) Breakdown of CLD Distance Means by Participant Situation Conditions.

Although a thorough statistical analysis was impossible, we can make some tentative observations. In particular, the CLD measured frontal robot approach distances tended to be smaller when the participants were standing or sitting in open space. Also the CLD measured approach distances tended to be smaller for the front right approach directions. The indicated approach distances for rear left and rear right may indicate that some participants allowed the robot to approach slightly closer from the rear left direction, as opposed to the rear right direction when seated or standing. However, it must be stressed that most participants did not use the CLD more than once or twice only, and these results must be treated with caution.

Summary and Discussion

Based on the responses from questionnaires (cf. Woods et al. 2006b), overall the front left and right approaches were rated by participants as the most comfortable for all the different scenario scenarios. The rear approaches and front direct approaches were generally rated as being the least comfortable across different scenarios. However, participants standing in the middle of the room actually preferred the direct frontal approach for task efficiency reasons. This is in contrast to the other scenarios, but could be due to the fact that the participant was standing and would have been taller than the robot, therefore not finding the robot intimidating in any way, in contrast to the seated conditions, where the participants were shorter than the robot.

Unfortunately, most participants did not use the CLD device regularly and thus severely restricted the data sample size. The sample size was too small to provide a good basis for proper statistical tests. The few tentative indications however, support some of findings obtained from the questionnaire data. This is an important finding and if confirmed it would allow some aspects of human users' preferences to be inferred from the simple CLD signaling device. The CLD could then actually be used while HRI trials are in progress and thus avoid or reduce the need for time consuming post trial questionnaires. There are also other advantages with regard to immediacy and not having to rely on participants' memories for their reactions to more complicated HRI scenarios. During the HRI trials the robot could also adapt its behavior based on the CLD data received.

These trial results do provide some further evidence reinforcing and extending results from previous studies (Woods et al. 2006a, 2006b; Walters et al. 2006) to four fundamental HRI scenarios which may occur in a typical robot 'serving' or 'object fetching' task scenario with standing and seated humans. However, the main lessons learnt from the work presented in this paper are: a) the need for a further development of the CLD methodology, and b) the demonstrated feasibility of the associated technique of automatically annotating HRI trial videos with CLD data in order to gain distance measurements. While the use of CLD annotated video data has been shown previously (Koay et al., 2006a; Koay et al., 2006b), in this paper we showed how this technique can be extended by using the video grid overlay to obtain both concurrent position and distance information of both robot and human directly from the video record. Future work will have to expand on these lessons and further develop methodologies to investigate human approach preferences and distances in naturalistic HRI scenarios.

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