Exploratory Study of a Robot Approaching a Person in the Context of Handing Over an Object

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Abstract

This paper presents the results from a Human-Robot Interaction study that investigates the issues of participants' preferences in terms of the *robot approach direction* (*direction*$_{RAD}$), *robot base approach interaction distance* (*distance*$_{RBAID}$), *robot handing over hand distance* (*distance*$_{RHOHD}$), *robot handing over arm gesture* (*gesture*$_{RHOAG}$), and the coordination of both the robot approaching and *gesture*$_{RHOAG}$ in the context of a robot handing over an object to a seated person. The results from this study aim at informing the development of a Human Aware Manipulation Planner. Twelve participants with some previous human-robot interaction experience were recruited for the trial. The results show that a majority of the participants prefer the robot to approach from the front and hand them a can of soft drink in the front sector of their personal zone. The robot handing over hand position had the most influence on determining from where the robot should approach (i.e *distance*$_{RAD}$). Legibility and perception of risk seem to be the deciding factor on how participants choose their preferred robot arm-base approach coordination for handing over a can. Detailed discussions of the results conclude the paper.

Introduction

The paper focuses on an exploratory study of a robot approaching a person in the context of handing over an object conducted at the University of Hertfordshire 'Robot House'. The aims of this study were twofold a) to understand, from the participants' point of view, how a robot should approach and hand over an object (i.e. a can) to a seated person, and b) to inform work carried out at the Laboratory for Analysis and Architecture of Systems at the Centre National de la Recherche Scientifique (LAAS-CNRS), in developing a Human Aware Manipulation Planner (HAMP) which takes account of human social factors and preferences. An overview of the issues regarding the progress and the development of a HAMP is provided.

In order to interact with humans in a robot companion context, robots not only need to be able to perform useful tasks and have adequate safety, but also need to engage in social interactions and behave in a socially acceptable manner (Dautenhahn et al., 2005; Fong et al., 2003). Hall (1966) demonstrated that social spaces play an important role in human-human relationships, and that the distance between two people, for example reflects their relationship. This has raised new issues regarding the development of an adaptive, socially aware, robot motion planner (i.e. for navigation and manipulation) in the presence of humans which is our long-term goal.

The first step towards reaching this long-term goal was to develop a Human Aware Navigation Planner and was addressed in a previous paper (Sisbot et al., 2005). Furthermore, the development of a Human Aware Navigation Planner was informed by research from user studies on social spaces and 'robot to human' approach directions (Koay et al., 2006a; Walters et al., 2005; Dautenhahn et al., 2006). The Human Aware Navigation Planner was later implemented into a real robotic system (Sisbot et al., 2006). Other equally important issues such as how a socially aware robot should stand in line, follow a person along a corridor and pass by a person along a hallway without inducing threat to the person are discussed in Nakauchi and Simmons (2000), Koay et al., (2006b) and Pacchierotti, Christensen and Jensfelt (2006) respectively.

In this paper we address the next step of developing a human aware 3D manipulation planner that will take human comfort and legibility into account to complement the navigation planner. Current robot manipulation systems (Topping and Smith, 1988; Sato and Kosuge, 2000; Yigit, Burghart and Woern, 2003) work primarily on feasibility and the goal of the motions without taking into account their effects on the human partner (i.e. comfort and legibility) and thus minimize the richness of interaction.

Human-Robot Interaction Trials

The trial was conducted in the living room of the University of Hertfordshire 'Robot House' (dedicated to Human-Robot Interaction (HRI) Studies in a domestic environment relevant to the Cogniron project) in the summer of 2006. The aim was to understand from the user's perspective how a robot with humanoid arms (see figure 1) should approach and hand over a can to a seated

Figure 1. The tall anthropomorphic appearance robot used in this study

person. The intention was to inform the design of a Human Aware 3D Manipulation Planner. Issues such as the *robot approach direction, robot base approach interaction distance, robot handing over hand distance, robot handing over arm gesture* and the coordination of both the robot approaching and *handing over arm gesture* were the main focus of this study.

Twelve participants aged between 21-41 (eight males and four females) were recruited for the study. They were recruited immediately after they finished taking part in a five-week long-term HRI experiment where they interacted with a robot twice a week on an hour per session basis (results from this long-term study will be presented in forthcoming papers).

Experimental Procedure

The first stage of the trials involved the participants interacting with the experimenters and the robot, regarding their preferences of how the robot should approach, stop and hand over an object.

This is in contrast to our previous experiments, e.g. (Sisbot et al., 2005; Dautenhahn et al., 2006), where the participants passively experienced and later chose from a set of preprogrammed robot approach behaviors. In those studies, large sample sizes allowed statistical analysis of participants' preferences assessed in post-trial questionnaires.

Here, the aim was to actively involve the participants in the study and interactively guide the creation of the robot handing over gesture. This was achieved by each participant individually informing the experimenters of their preferred:

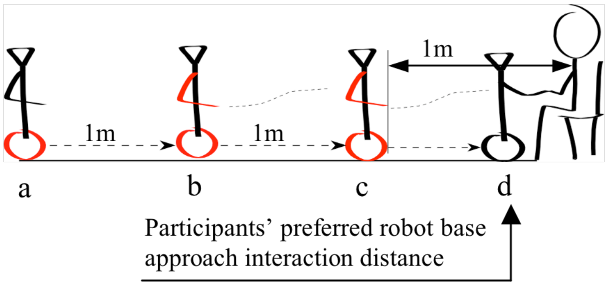


Figure 2. The four different arm-base approach coordination styles.

- *robot approach direction* ($direction_{RAD}$); where the robot should approach from.
- *robot base approach interaction distance* ($distance_{RBAID}$); the distance at which the robot should stop, relative to the participant's position.
- *robot handing over hand distance* ($distance_{RHOHD}$); the robot hand distance relative to the participant's position.
- *robot handing over arm gesture* ($gesture_{RHOAG}$); the specific ways the robot hands over the object. Takes into account the $distance_{RHOHD}$.

Each $gesture_{RHOAG}$ was then implemented into four specifically designed arm-base approach coordinations that focus mainly on legibility and safety (figure 2):

I. Robot starts approaching from position A, heading towards the participant, only after the $gesture_{RHOAG}$ is completed.

II. Robot starts approaching from position A, heading towards the participant but only executes the $gesture_{RHOAG}$ while moving from position B to position D.

III. Robot starts approaching from position A, heading towards the participant but only executes the $gesture_{RHOAG}$ while moving from position C to position D.

IV. Robot starts moving from position A, heading towards the participant but only starts executing the $gesture_{RHOAG}$ after it has stopped at position D.

In all cases, the direction the robot was approaching from was the $direction_{RAD}$ for each participant. Position D was derived from the $distance_{RBAID}$ for each participant.

The participants experienced each of the four predefined robot arm-base coordination styles, tailored to their preferences, and were asked to select the one they most preferred during the second stage of the trials.

The participants, as part of the above-mentioned long-term study, had also completed questionnaires in which they were asked to rate their own personality traits using the Big Five domain scale from Goldberg (1999), which we have used in previous HRI studies (Syrdal et al., 2006, 2007).

Results

Results from the trials are presented in the categories of direction, distance, height and robot handing over behavior.

Direction

The results show that 58.3% of the participants prefer the robot to approach from the participant's front while 25% prefer the robot to approach from the participant's right front. Moreover, 8.3% prefer a robot approach from the participants' right, 8.3% prefer the left front. We found that 75% of the participants prefer the robot to hand them the object from directly in front, 17% prefer the robot to hand the object at their right front and 8% prefer the robot to hand them the object to their left front. The summary of these two results shows that the direction where the robot should hand over an object has most influence on determining where the robot should approach. As shown in figure 3, the robot base approach interaction position and its handing over hand position are likely to be in the same region (i.e. at 36 degree intervals starting from participant' right to participant's left) during the handing over process (Pearson's *r*=19.111, *p*=.004).

Distance

The mean preferred $distance_{RBAID}$ for the whole sample was 66.8cm (SD=6.96cm). The minimum distance was 58cm, and the maximum distance was 82cm. Assuming the distances between the participants and the robot should be measured from participants' chests (i.e. center of the chair), the results show that the participants prefer to interact with the robot within their personal zone (Hall, 1966), which is mainly reserved for conversation between friends.

Two clusters of the preferred $distance_{RBAID}$ were found (see figure 4a) which centered at 72.42cm and 61.25cm. Members in the two clusters differed on the personality traits Agreeableness and Intellect/Openness. The mean score for Agreeableness was 3.53 (SD=.53cm) in cluster 1

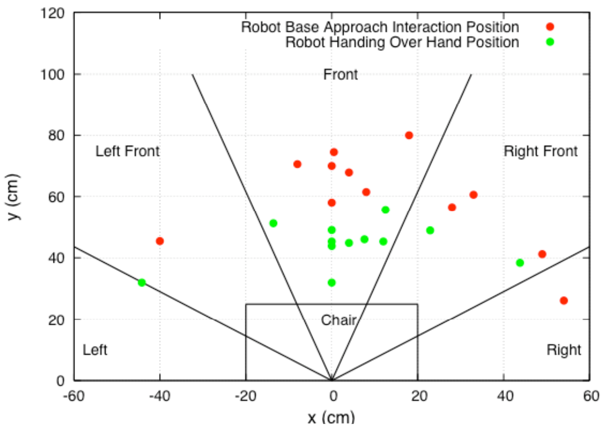
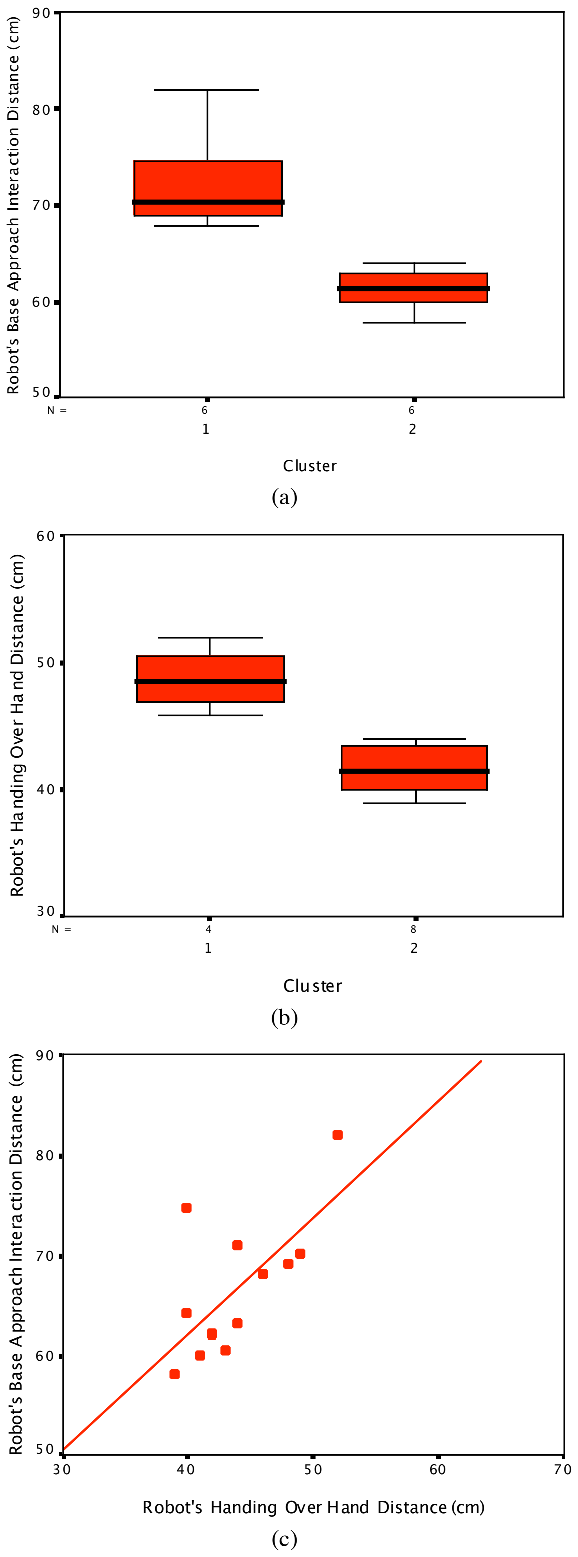


Figure 3. Participants' preferred robot' base and hand approach interaction positions relative to the center of the chair used by the participants during the trial.



(a)

(b)

(c)

Figure 4. The graphs show (a) Two clusters of the participants preferred robot's base approach interaction distances, (b) two clusters of participants preferred robot's handing over hand distances, and (c) positive correlation of robot base approach interaction distances and robot handing over hand distances.

and 4.16 (SD=1.02cm) in cluster 2. For Intellect/Openness, the mean score was 3.40 (SD=.49cm) in cluster 1, and 4.18 (SD=.44cm) in cluster 2. Mann-Whitney U tests found these differences to be significant for Intellect/Openness (U=5, p<.05) and approaching significance for Agreeableness (U=6, p=.054).

Two clusters of the preferred $distance_{RHOHD}$ were found (see figure 4b) which centered at 48.75cm and 41.63cm. Members in these two clusters also differed on the personality traits Agreeableness and Intellect/Openness. The mean score for Agreeableness was 3.25 (SD=.41 cm) in cluster 1 and 4.15 (SD=.58 cm) in cluster 2. For Intellect/Openness, the mean score was 3.18 (SD=.44 cm) in cluster 1, and 4.10 (SD=.40 cm) in cluster 2. Mann-Whitney U tests found these differences to be significant for both Intellect/Openness (U=2, p<.05) and Agreeableness (U=2, p<.05).

The results also show that the participants preferred $distance_{RBAID}$ were positively correlated with participants preferred $distance_{RHOHD}$ (Spearman's rho=.568, p=.027) as illustrated in figure 4c. This may imply that participants who preferred close approaches by the robot base also tended to allow the robot hand to reach closer towards them while handing over a can. However participants who preferred further $distance_{RBAID}$ also preferred to reach out towards the robot hand themselves, rather than allowing the robot hand to reach closer toward them while handing them a can.

Height

Regarding the robot's handing over hand height, the results show that participants' preferences are equally spread with mean value of 78.9cm and median value of 79cm staying close with each other between a minimum height of 73cm and a maximum height of 86cm.

No correlations were found between participants' height and preferred $distance_{RBAID}$ (Spearman's rho=-.375, p=.127), participants preferred $distance_{RHOHD}$ (Spearman's rho=.046, p=.444) and participants preferred robot handing over hand heights (Spearman's rho=.134, p=.339).

Most of the participants (i.e. 10 were right handed, 1 was ambidextrous) preferred the robot to hand them the object with its right hand (92%). Only one participant (right handed) preferred the robot to use its left arm.

Robot Arm-Base Approach Coordination

The results show that the majority of the participants preferred the robot arm-base approach coordination type III, followed by type IV and lastly type II with 58.3%, 33.3% and 8.3% respectively. None of our participants preferred robot arm-base approach coordination type I.

A Human Aware Manipulation Planner

As already discussed in the introduction, current robot manipulation planning systems deal only with the goal configuration and the feasibility of the motions without taking into account how they are perceived by the human partner.

We are developing a planner that is based on new concepts and protocols such as reasoning about the human's field of view, attention, preferences (left/right handed, etc), current state (sleeping, sitting, working, etc.) as well as the robot's field of view, kinematics and dynamics.

Our aim is to build a generic 3D manipulation planner which applicable to various robot structures:

- is able to work with a model of the human that can be quite complex (kinematic structure with head, body and limbs).
- is able to include computation on the visibility of the human and its reachability (geometric reasoning based on kinematic representation of the human).
- introduces costs, protocols and preferences in terms of motion of the platform, the arm and the head based on the user studies.

There are two key concepts that must be considered when planning a human-friendly manipulation:

1) Visibility of the motion:

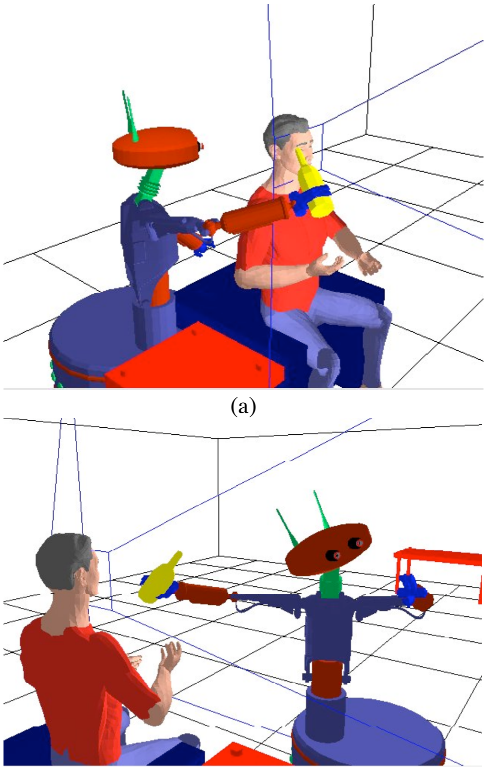
- The robot must move in a way that guarantees its visibility (total or partial) from the human's perspective (see figure 5a).
- In a real manipulator robot, one must consider the correct targeting of its cameras to ensure motion control and environment monitoring. For example, an object carried by the robot must not be hidden from the camera by the robot arm. Although it may appear that this property serves only the functioning of the robot, maintaining a view at the object during the interaction helps the human to understand and predict the robot's attention.

2) The posture of the motion:

The motion should reflect the intention of the robot in a step-by-step manner by controlling the type of the motion, the orientation of the robot head and visibility of the object and of the human (Figure 5b).

The kinematics of the robot and the human partner must be modeled precisely and the redundancies caused by their structures must be dealt with. To reduce the complexity of this problem, roadmap methods will be used to plan the robot's motions. Utilization of roadmap methods to produce comfortable motions provides not only an intelligent choice of nodes, but also a good choice of local paths connecting these nodes. We are using Generalized Inverse Kinematics (GIK) (Yamane and Nakamura, 2003; Baerlocher and Boulic, 2004) to produce local motions between the nodes of the roadmap. Although this method is computationally expensive, it has certain advantages:

- Not dependent on the robot structure: The GIK method only needs a Jacobian matrix easily obtainable from its structure. This property makes


(a)

(b)

Figure 5. (a). Even though the object is visible from the human's perspective, if the robot is hidden from the human partner, then the interaction is perceived as uncomfortable, (b). The robot's motion must be predictable. In this figure we see that even though the robot and the object are visible to the human, this unusual motion during the interaction causes uncomfortable interaction.

this method readily portable from one robot to another.

- Multiple tasks with priorities: The GIK method allows us to define additional tasks next to the main task. Therefore the robot not only accomplishes its task, but can also take account of additional motion constraints during its motion. For example, during its motion to pick up an object (main task), it can assure the visibility of the object by moving camera joints (additional tasks). Each task has a priority and a highly redundant robot structure can perform multiple tasks at the same time with the ability to guarantee accomplishing the main task.
- Customizable according to various criteria: Various costs, potentials or postures can be used as an additional criterion to the main task. This property can allow the manipulation planner to inherit the costs from the HAMP grids and thus make these two planners heavily connected.

Produced motion is then transmitted to the limited jerk controller (Aguilar and Sidobre, 2006) which follows the plan with a smooth motion by controlling velocity and the jerk of the robot arm.

The next step in the development of the Human Aware Motion Planner will be to introduce roadmaps which will contain GIK local paths to obtain a complete motion. The Navigation and Manipulation planners will be linked in order to obtain a continuous motion where the arm and the base of the robot move together.

Conclusions

This study shows that a majority of the participants have a strong preference to interact with the robot in the front sector of their personal zone; more specifically, for the robot to approach them and also to hand them a can, while directly in front of them.

This is in contrast to our previous findings (Walters et al. 2007) which have shown that the majority of the participants disliked the robot to approach from the front. In retrospect, this can be explained due to the fact that the previous group of participants had no experience of interacting with the robots, prior to the trials. At the time, it was hypothesized in Walters et al. (2007) that the participants might have found the robot frontal approach to be unsafe, intimidating or even aggressive and invasive compared to the side approach. Considering the current findings, the results indicate that the cohabituation effects between the participants and the robot may play an important role in developing HRI preferences.

Figure 3 indicates that participants preferences of the robot handing over hand position has the most influence on determining where the robot should approach from during the interaction. This is supported by statistical tests which show a strong correlation between participants preferred $\mathit{distance}_{RBAID}$, and the direction where the robot handing over hand position should be.

Regarding participants preferred robot's handing over hand height when handing over a can to a seated person, no correlation was found between participants height. However the data did indicate that participants prefer the robot handing over hand height to be just below their chest areas while they were seated.

In terms of distances we have show that the results can be classified into two clusters (i.e. participants who prefer to interact with the robot at close distance and participants who prefer to interact with the robot at a further distance). Some differences in participant personality depending on cluster memberships were found. These suggest that participants scoring higher in Agreeableness and Intellect/Openness score tend to prefer both the robot to approach closer, and the handing over interaction to take place closer to the participant, than participants with lower scores in these two traits. However the means difference between each cluster memberships were relatively small (i.e. less than 12cm). Therefore more trials are needed to investigate two new hypotheses:

1. At a higher conceptual level, results suggest that participants' personality can influence their

preferred robot base and hand approach interaction distances. How should HRI accommodate these differences?

2. At a more practical level, do the differences between these cluster memberships influence participants feelings of comfort during the interaction?

In terms of robot arm-base approach coordination for handing over a can, a large majority of the participants (58.3%) prefer the robot to use robot arm-base approach coordination type III for its legibility and lower perception of risks compare to type I and II, followed by a smaller percentage (33.3%) who prefer robot arm-base approach coordination type IV for its perception of the least risk. This strongly indicates that legibility and safety are the main concern for our participants when the robot is approaching them for interaction. The perception of risks by the participants for arm-base approach coordination type I (i.e. approach with outstretched arm) and type II seems to be higher than type III and IV. Therefore none of our participants prefer type I and only one participant prefered type II. The perception of risks seems to play a big part for participants choosing arm-base approach coordination type III over type II. Both types were designed to focus on legibility with the only difference that type II starts its handing over gesture a meter further. Hence the perception of risk for a robot approaching with an outstretched arm were probably higher than that of type III. Further research needs to elaborate on these results, investigating in more depth issues of users' personality, as well as safety and legibility issues in HRI scenarios relevant for a robot companion.

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