How May I Serve You? A Robot Companion Approaching a Seated Person in a Helping Context

Kerstin Dautenhahn, Michael Walters, Sarah Woods, Kheng Lee Koay, Christopher L Nehaniv, Emrah Akin Sisbot, Rachid Alami, Thierry Simeon

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How May I Serve You? A Robot Companion Approaching a Seated Person in a Helping Context

K. Dautenhahn, M. Walters,
S. Woods, K. L. Koay, C. L. Nehaniv,
University of Hertfordshire,
College Lane,
Hatfield, UK, AL10 9AB
+44 (0) 1707 285113
K.Dautenhahn@herts.ac.uk

E. A. Sisbot, R. Alami,
T.Siméon
LAAS-CNRS
7, Avenue de Colonel Roche,
31077 Toulouse, FRANCE
+33 (0) 5 61 33 63 46
Emrah.Akin.Sisbot@laas.fr

ABSTRACT
This paper presents the combined results of two studies that investigated how a robot should best approach and place itself relative to a seated human subject. Two live Human Robot Interaction (HRI) trials were performed involving a robot fetching an object that the human had requested, using different approach directions. Results of the trials indicated that most subjects disliked a frontal approach, except for a small minority of females, and most subjects preferred to be approached from either the left or right side, with a small overall preference for a right approach by the robot. Handedness and occupation were not related to these preferences. We discuss the results of the user studies in the context of developing a path planning system for a mobile robot.

Categories and Subject Descriptors
A.m [**Miscellaneous**]: Human Robot Interaction – *Social Robots*

I.2.9 [**Artificial Intelligence**]: Robotics – *Mobile robots*

General Terms
Human Factors,

Keywords
Human-robot interaction, social robot, social spaces, personal spaces, user trials, live interactions

1. INTRODUCTION
If robots are to be used in office and domestic environments, they will have to encounter and interact with people. They must survive and carry out tasks in a disordered and unpredictable environment, safely and effectively. This paper presents the results from Human Robot Interaction (HRI) trials carried out at the University of Hertfordshire (UH). These results have then been used to inform and guide work carried out at the Laboratory for Analysis and Architecture of Systems at the Centre National de la Recherche Scientifique (LAAS-CNRS), to develop a task planning, motion planning, and control system that incorporates human social factors and preferences.

The work presented in this paper contributes to the COGNIRON Project [2005]. Part of this research into a cognitive robot companion investigates socially interactive robots [7] from a human-centred perspective, i.e. how robots could be useful in domestic environments; in particular the roles, tasks, and social behaviour(s) that will be necessary for robots to exhibit in order to integrate into everyday domestic situations. In order to study human-robot relationships, HRI trials using carefully devised test scenarios are conducted [18], where human responses and opinions can be collected using a variety of methods. A number of previous live HRI trials with human scaled PeopleBot^{TM} robots have been carried out [6, 17, 19, 20]. Other researchers have also investigated similar HRI trials with human sized robots including Dario et al. [4], Severinson-Eklundh et al. [16], Kanda et al. [9] and Hinds et al. [8].

Once the desired behaviour(s) for sociable robots capable of competent human-robot interactions are known, the challenge is then to incorporate the results into mobile robot path planning algorithms and control systems. At LAAS-CNRS progress has been made towards a motion planning framework that will allow the implementation of key criteria and parameters that can incorporate these results into the control system of a mobile robot that can be applied to human-centred environments. The presence of humans raises new issues for motion planning and control since the human's safety and comfort must be taken into account. The claim here is that a human-aware motion planner must not only consider safe robot paths, but also plan good, socially acceptable and legible paths.

There are a number of contributions in the literature where humans and robots co-exist in the same environment. These studies have frequently focussed only on the safety of the human [2, 10, 11, 21] and have failed to take *human comfort* into account. The planner presented here explicitly takes into account the human partners' safety and comfort by reasoning about accessibility, visual field, posture, gaze direction, relative distance to the robot and potential shared motions. Although several authors have proposed motion planning or reactive schemes with a consideration for humans, there is no contribution that has tackled this whole problem.

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2. The Live HRI Trials

This section presents results from two live HRI trials. First, a human-robot interaction *demonstration trial* event, which was run as part of an informal evening event at the AISB'05 Convention held at University of Hertfordshire in April 2005, and secondly, *follow-up trials* carried out in a controlled laboratory set-up, to re-test the results gained from the demonstration trial.

2.1 The HRI Trial Method

The trials were both carried out in converted seminar rooms where the scenario involved a robot using three different approach directions (front, left and right) to bring a seated subject an object (a TV remote control). The main aim of both trials was to establish subjects' preferences for the different robot approach directions. The demonstration event was conducted as part of an evening of entertainment for convention delegates, and involved different robot demonstrations. Spectators were present during the trials which were performed under non-laboratory conditions using 38 volunteers from the convention. The follow up study was carried out under controlled conditions with 15 subjects, and one of the main aims of this trial was to re-test the results obtained from the informal study.

2.1.1 The Trial Areas

The trial set-up was virtually identical for both trials and resembled a simulated living room with a chair and two tables. The subject was seated in the chair, which was positioned halfway along the rear wall (point (9), Fig.1), throughout the trial. To the left front, and right front of the chair, two tables were arranged (with room for the robot to pass by) in front of the chair. One of the tables had a television placed upon it; the other had a CD Radio unit. The robot was driven under direct remote control to the appropriate start position by an operator, but the robot's approaches to the subject were fully autonomous. The operator was seated at a table in the far corner of the room. Subjects were told that the robot would be controlled by the operator while it was driven to the three start positions, but would be approaching them autonomously to bring them the TV remote control. This was reinforced as the operator made notes and did not press any of the robot control keys (on the robot control laptop) while it approached the subject (Figure 1). The robot carried the remote control in a small basket suspended between the fingers of the lifting gripper. The remote control was placed in the basket prior to each experimental run. For each approach trial, the subject took the remote from the basket then replaced it ready for the next approach.

2.1.2 The HRI Trial Scenario

The same scenario was used for both HRI trials, introduced by the experiment supervisor. The context explained to the subjects was as follows: the subject had arrived home, tired after a long day at work and rested in an armchair (point (9), Fig.1). After looking around for the TV remote control, the subject then asked the robot to fetch it for them as they were too tired to get up. The robot then brought the remote control to the subject. It was explained to the subject that the robot was new to the household and it was necessary to find out which approach direction the subject preferred; either from the front (2), the left (1) or the right (3). The three possible paths taken by the robot are shown in Fig. 1. In order to justify the scenario of the robot fetching the remote control, one of the tables had a (switched off) TV set upon it. The other table had a CD-Radio unit. Our expectations prior to the trials were that subjects would prefer the approach from the front, since the robot was then fully visible at all times. Since many subjects, in particular in the demonstration trial, had never seen the robot before we assumed that they would feel most secure, comfortable, and 'in control' when the robot was fully visible so that its behaviour could be monitored easily.

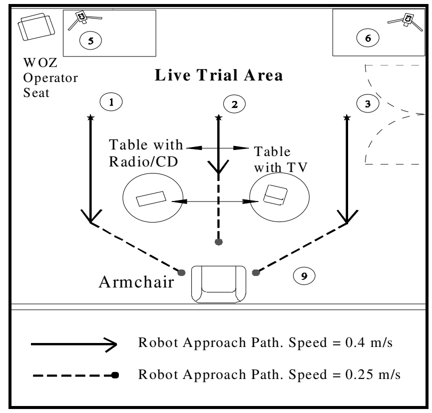

Figure 1. Live Trial Area

Figure 2. Examples of the demonstration HRI trial

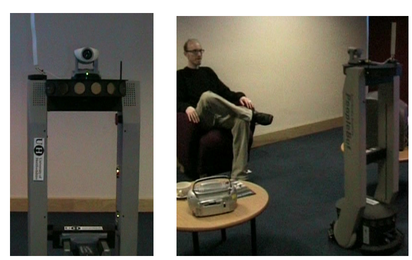

Figure 3. Example of the follow-up HRI trial.

2.1.3 Experimental Conditions

We were aware that the TV might be a natural focus of subjects' attention and may have influenced the choice of preferred robot approach direction. Therefore, for the controlled lab condition, half the trials were carried out with the TV on the left hand table, and the other half with the TV on the right hand table. Each subject experienced the robot approaching from three directions: front, left and right. To avoid any order effects, a counterbalanced order sequence covering all six possible permutations of the three robot approach directions was used. For the demonstration event, subjects experienced each approach direction only once, and for the controlled follow-up trials, each subject experienced the three robot approach directions twice, in a counterbalanced order.

2.1.4 Subject Sample Sets:

For the demonstration trial, 21 males (54%) and 18 females (46%) participated. The mean age of subjects was 36 years (range: 22-58). Thirty five subjects (95%) were right handed, and 2 subjects (5%) were left handed. All were delegates at the AISB'05 Convention. Fifteen subjects (9 (60%) males; 6 (40%) females) participated in the follow-up study. The mean age of this sample was 33 years (range 21-56 yrs). Only one subject was left handed. Four subjects were secretarial staff, 5 subjects were MSc students studying 'Artificial Intelligence', and the remaining 6 were research staff in the Computer Science Department at University of Hertfordshire. No subjects had previous exposure to the robots used in the trial. In the demonstration trial, some subjects had not sat straight in the chair (see Fig. 2). In the follow-up study subjects were made to sit straight with their feet to the front of the chair.

2.1.5 Procedure

For both trials, subjects completed a short introductory questionnaire to gain the necessary consent, and demographic details. At the end of each trial a semi-structured questionnaire was used to assess subject attitudes and preferences for the different robot approach directions and approach speed, as well as practicality issues. The questionnaires used for the follow-up trials were more extensive and included questions about the robot stopping distances, comfort levels and practicality for the different approach directions, rated according to a 5-point Likert scale. Subjects also participated in a semi-structured interview after the follow-up trial. The interview was carefully designed to eliminate leading questions. The main purpose of the structured interview was to assess subjects' views about the trial procedures and methodology, and find out how the trial could be improved from the participants' point of view. The subjects' reactions to both HRI trials were recorded by a single tripod mounted camera placed at an appropriate point at either (5) or (6) in Fig. 1.

2.2 Demonstration Trial Results

2.2.1 Overall Approach Direction Preferences:

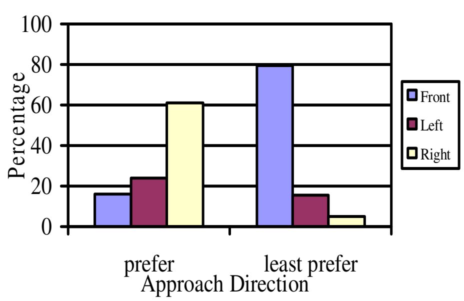

Figure 4. Demonstration trial: Robot to human approach direction preferences.

Figure 4 illustrates that 60% (N: 23) of subjects stated that they preferred the right robot approach direction, followed by 24% (N: 9) preferring the left approach and just 16% (N: 6) preferring the front approach. An overriding majority of subjects stated that they least preferred the frontal robot approach direction (N: 31, 80%). Very few subjects least preferred the left and right approach directions.

2.2.2 Gender Differences & Approach Direction Preferences

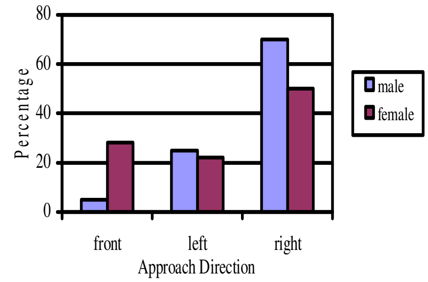

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Figure 5. Male and female approach direction preferences

Chi-square cross-tabulations revealed a significant trend between gender and the preferred robot approach direction (X^2 (2, 38) = 3.77, p = 0.1). More females stated that they preferred the front robot approach direction compared to males, and more males preferred the right robot approach direction compared to females (see Figure 5). A significant relationship was found between gender and least preferred robot approach direction (X^2 (2, 39) = 7.09, p = 0.03). Significantly more males stated that they least preferred the front robot approach direction compared to females (males: 95%, females: 61%). More females stated that they least preferred the right robot approach direction compared to males (males: 0%, females: 11%).

2.2.3 Age, Handedness, and Approach Direction Preferences

Chi-square cross-tabulations revealed no significant relationships between age, handedness and approach directions preferred and least preferred.

2.2.4 Approach Distance

76% (N: 28) of subjects stated that the distance between them and the robot (0.5m ±0.1m) was 'about right', followed by 19% (N: 7) who felt that the robot was to 'too far' from them. Only 5% (N: 2) of subjects stated that the robot approached them too closely.

2.2.5 Practicality of Approach Directions

In addition to subjects rating which robot approach direction they preferred, ratings were given for how 'practical' they thought each approach direction was for the given task of delivering a TV remote control, according to a 5-point Likert scale (1 = not practical at all to 5 = very practical). A Friedman test for ordinal data illustrated that the rankings for approach direction practicality were significantly different from each other (X^2 (39, 2) = 12.11, p < 0.01). The mean rankings indicated that the front approach direction (mean ranking = 1.63) was rated as the least practical, and the right approach the most practical (mean ranking = 2.33), followed by the left (mean ranking = 2.04) approach direction.

2.2.6 Comfort Ratings of Approach Directions

Subjects were asked to rate how comfortable they felt with the different robot approach directions trials according to a 5-point Likert scale (1 = very uncomfortable, 5 = very comfortable). A Friedman test showed that the comfort level rankings for approach directions were significantly different from each other (X^2 (39, 2) = 29.38, $p < 0.001$). The mean rankings highlighted that subjects were the least comfortable with the front (mean ranking = 1.37) robot approach direction, and the most comfortable with the right approach direction (mean ranking = 2.49), followed by the left (mean ranking = 2.14).

2.3 Follow-Up Trial Results

2.3.1 Approach directions most and least preferred

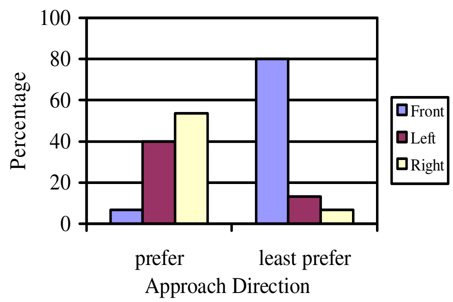

Figure 6. Follow-up trial: Least preferred and most preferred robot to human approach directions.

Results of the follow-up approach direction robot trials under laboratory conditions clearly demonstrated that the least preferred approach direction was the front approach. The right approach direction was the most preferred. These results are highly consistent, with the demonstration trial results (Figure 6).

2.3.2 Robot Distance from the Subject

For the robot's front approach direction stopping distance, 53% (N = 8) of subjects rated that the robot's stopping distance was too close. 27% (N = 4) of subjects rated that the robot's stopping distance was about right, and 20% rated that robot's stopping distance was too far. These results seem to indicate that a near majority of subjects rated that the front approach stopping distance was too close. In the case of subjects who rated the stopping distance as being too far for the front approach, we observed that these subjects usually had their legs stretched out in front of them causing the robot to stop when it reached the subject's feet rather than their arm for them to reach the TV remote control (due to the robot's stopping safety mechanism which had to be operational due to safety considerations). During the robot's approach from the left direction, 80% (N = 12) stated that the stopping distance was about right and 20% (N = 3) rated the stopping distance as being too far. During the robot's approach from the right of the subject 60% (N = 9) of subjects rated the stopping distance as about right, and 40% (N = 6) rated it as too far. It is interesting to note that no subjects thought the robot approached too closely from either left or right approach directions.

2.3.3 Robot's Speed during the Trial

The robots final approach speed to the subject was approximately 0.4 to 0.25 m/s, but was not finely controlled due to the inbuilt safety speed limiting mechanism. When subjects were asked to rate the robot's approach speed, 60% (N: 7) of participants rated that the speed was about right, and 40% (N: 6) of subjects rated that the robot's speed was too slow. None of the subjects rated that the robot's speed was too fast during the trials.

2.3.4 Practicality and Comfort of the different Robot Approach Directions

The front approach direction received the lowest practicality ratings for both the live and video trials. The right approach direction received the highest ratings of practicality followed by the left approach. The lowest mean comfort levels were found for the front robot approach direction. The highest comfort level rating was found for the right approach direction followed by the left approach direction. No significant differences were found between most preferred approach direction and least preferred approach direction for gender, subject handedness (whether subject was left or right handed), and occupation.

2.4 Combined Results of Demonstration & Follow-Up Trials

In light of the comparable HRI trial methodologies and the high degree of agreement between the results from the informal demonstration trials and formal follow-up trials, the results from both trials were combined to form one dataset from the 55 subjects who participated in both trials. Thirty males (56%) and 24 females (44%) in total participated in the robot approach direction trials. The mean age of subjects was 36 years (range: 21-58, SD: 11.54). Forty nine subjects (94%) were right handed, and 3 subjects (6%) were left handed.

2.4.1 Trial Preferences:

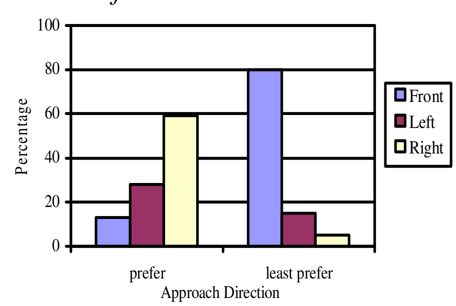

Figure 7. Combined trial results: Overall robot to human approach direction preferences

Figure 7 illustrates that 59% (N: 31) of subjects stated preferring the right robot approach direction, followed by 28% (N: 15) who preferred the left approach, and just 13% (N: 7) preferred the front approach. An overriding majority of subjects stated least preferring the front robot approach direction (N: 43, 80%). Few subjects least preferred the left and right approach directions.

2.4.2 Practicality of Approach Directions

A Friedman test for ordinal data illustrated that the rankings for approach direction practicality were significantly different from each other (X^2 (54, 2) = 21.87, $p < 0.001$). The mean rankings indicate that the front approach direction (mean ranking = 1.55) was rated as the least practical, and that the right approach was the most practical (mean ranking = 2.34), followed by the left (mean ranking = 2.11) approach direction.

2.4.3 *Comfort Ratings of the Approach Directions*

Results from a Friedman test showed that the comfort level rankings for approach directions were significantly different from each other (X^2 (54, 2) = 47.78, $p < 0.001$). The mean rankings highlight that subjects were the least comfortable with the front (mean ranking = 2.43) robot approach direction, and the most comfortable with the right approach direction (mean ranking = 4.15), followed by the left (mean ranking = 3.76).

2.4.4 *Gender Differences*

Chi-square cross-tabulations revealed a significant association between gender and the robot approach direction preferred (X^2 (2, 53) = 5.83, p = 0.05). More females stated preferring the robot front approach direction compared to males, and more males preferred the right robot approach direction compared to females (See Figure 8). A small significant relationship was found between gender and least preferred robot approach direction (X^2 (2, 54) = 5.72, p = 0.06). More males stated least preferring the front robot approach direction compared to females (males: 90%, females: 67%). More females stated least preferring the left (males: 10%, females: 21%) and right robot approach direction compared to males (males: 0%, females: 13%). Independent measures t-tests revealed a trend for males (M = 4.37) to rate the right robot approach direction as more comfortable compared to females (M = 3.88) (t (52) = 1.74, p = 0.08). No further significant gender differences were revealed for comfort ratings of the front and left robot approach directions.

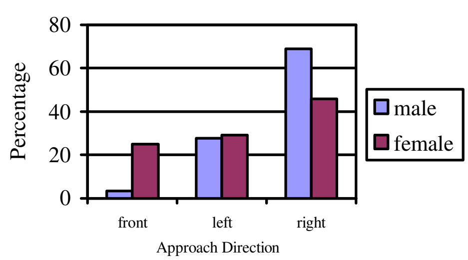

Figure 8. Combined results: Male and female preferences

Independent measures t-tests were calculated to examine gender differences and ratings of the practicality of the robot approach directions. Significant differences were found for the practicality of the front approach direction (t (52) = -2.46, p = 0.02). Females rated the front approach direction as significantly more practical compared to males (males M = 2.60, females M = 3.38). No further significant differences were found between gender and practicality ratings for the left and right approach directions.

2.4.5 *Age, Handedness, and Approach Direction Preferences*

Chi-square cross-tabulations revealed no significant relationships between age, handedness, approach directions most and least preferred, comfort ratings of the approach directions, and practicality ratings of the approach directions.

2.4.6 *Comments made by Subjects about the Three Robot Approach Directions.*

Subjects were asked to provide details about the reasons for preferring and least preferring particular robot approach directions. The most frequently cited comments are provided in tables 1 and 2.[1]

Table 1. Reasons why subjects preferred a particular approach direction.

Preferred Front Approach Direction
Front approach direction was easy to reach for the TV remote control
The effort needed to reach for the remote control was the least, but this was still not close enough
Preferred Left Approach Direction
I felt the most relaxed and comfortable during this approach
Preferred this approach as I am left handed
This approach was the quickest and most direct
This approach felt the most natural
It was the most convenient for the robot to approach this way.
Preferred Right Approach Direction
I felt the most comfortable with this approach
This approach seemed the most natural
I am right handed, so it was the easiest way to take the remote control
This approach seemed to be the quickest
This approach because it was always in my field of vision

Table 2. Reasons why subjects least preferred a particular approach direction.

Least Preferred Front Approach Direction
I had to move forward to reach for the remote control, the robot was too far away from me
This approach was slightly threatening
This approach was just a little bit too close for comfort
Seemed too aggressive
The robot was always looking a me
I was concerned about the robot running into me during this approach
This approach was intimidating
Least Preferred Left Approach Direction
Didn't like left approach as I am right handed
It was difficult for me to reach for the remote control
I felt awkward reaching across with me left hand
It felt like I had to reach further for the left approach
The robot was not in my line of vision during the left approach
Least Preferred Right Approach Direction
Least preferred this approach because I am left handed
The robot felt like it was behind my back during this approach

Implications of User Studies for Robot Motion Planning

Today, classical motion planning methods [12] are quite efficient at locating feasible paths. However, the presence of humans in the environment drastically changes the notion of acceptable paths. In a human-robot interaction context, the computed paths do not only need to be collision-free but must also take into account human

[1] Due to space limitations, only the most frequently cited comments are shown.

comfort. This is illustrated in figure 9, which shows two paths produced by a classical motion planner. Both paths are inconvenient since one path passes too close to the wall, causing the human to be surprised, and the other passes behind the human resulting in discomfort. The HRI studies reported in the previous section, and others [1, 13, and 19] highlight a number of properties that must be taken into account when dealing with humans. Only limited studies have considered comfort and legibility issues, often in an ad hoc manner. A new technique is described that integrates additional constraints in a more generic way. In these steps of our work, we assume that the final positions of the paths are already calculated.

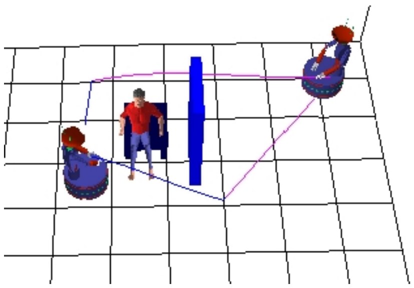

Figure 9. Two paths found by classical motion planning systems

We introduce three criteria to the motion planning stage to ensure safety and comfort. The robot must take into account these three criteria at the planning stage along with the more common aspects of path planning such as obstacle avoidance. Each criterion is represented by human-centred costs stored in a 2D grid:

Safety Criterion: This focuses on ensuring safety by controlling the distance between the robot and human. The robot, if possible, must avoid approaching the human too closely, and in some cases (i.e. no physical interaction) the robot must not be able to pass through a certain perimeter around the human. However, the robot must be able to approach the human to allow interactions to occur (for example to pass an object to a human). Hence, this distance between the robot and the human is not uniform and fixed, but depends on the type of human-robot interaction, in addition to the human preferences, and physical abilities. For instance, the user studies presented above are reflected by a configuration of costs that favours approach motions by the side (Fig 10).

Visibility Criterion: Human comfort is a key issue when dealing with HRI scenarios, and some properties can be extracted from this issue. In particular, humans generally feel more comfortable when the robot is within their field of vision. Therefore, a "visibility criterion", is used to help the robot to stay, during its motions, in the human's field of view. The visibility grid is constructed according to costs reflecting the effort required by the human to get the robot in his field of view. Grid points located in a direction for which the human has only to move his eyes have a lower cost than positions requiring head turning in order to get the robot in the field of view. Also, when the robot is far away from the human, the effect of visibility must decrease, and beyond a certain distance it must be negligible.

Hidden Zones: In the grids presented above, the costs are calculated without taking into account obstacles in the environment. However, obstacles in close vicinity to the human can have various effects on safety and visibility issues. If the robot is behind an obstacle, the human might feel comfortable because the obstacle would block the direct path between the human and the robot. Therefore, the safety criterion must be cancelled in zones located behind the obstacles. In contrast, as the robot passes behind an obstacle and becomes hidden, and the human cannot see the robot, the visibility costs no longer correspond to physical realities. To handle this issue, we introduce a further criterion termed, "hidden zones criterion". This criterion helps to determine better costs for positions hidden from the human by obstacles. An important effect of obstacles for human comfort is the "surprise factor". When the robot is hidden by an obstacle close to the human, and suddenly appears in the human field of vision, it can cause surprise and possibly fear. To avoid this effect, we must discourage the robot to pass behind an obstacle too closely, and must allow it to get into the human's field of view when sufficiently far from the human. This can be done by adding costs to the zones hidden from the subject's view by the obstacles. The costs in the hidden zone grid are inversely proportional to the distance between the human and the robot so that the robot chooses to keep a distance from back sides of the obstacles that are close to humans.

Once the safety, visibility, and hidden zones grids have been computed (Fig. 10), they are merged into one single grid where the robot will search for a minimum cost path.

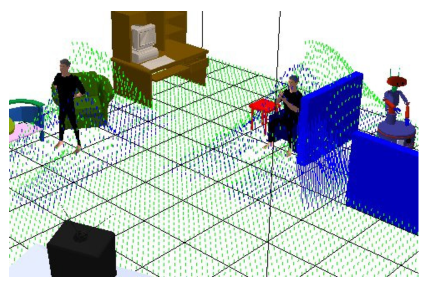

Figure 10. The "safety", the "visibility" and the hidden zones" grids. The height of a point corresponds to the cost of that point. The grids were modified to correspond to the results of the user studies.

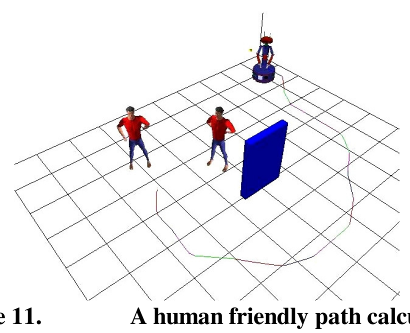

Figure 11. A human friendly path calculated automatically by the planner. Note the robot does not choose the shortest path and prefers a path that avoids it "to burst" near the human.

Different ways, depending on the task and on the balance between criteria, can be used to aggregate the grid costs.

For example, for an urgent task, the importance of the visibility grid is less than the safety grid so that the robot does not take visibility largely into account. Once the final grid is computed, the cells corresponding to the obstacles in the environment are labelled as forbidden and an A* search is performed to find minimum-cost path between two given positions of the robot. Since only crossing the obstacles and humans are forbidden, with this algorithm we guarantee to find a path if it exists.

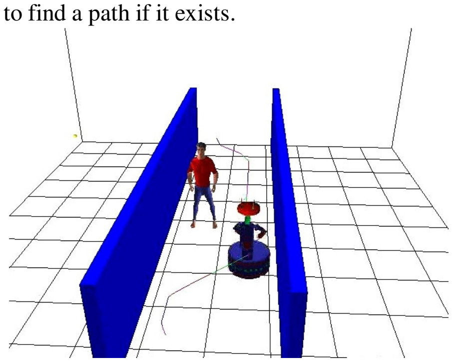

Figure 12. A Hallway scenario. The planner automatically plans a trajectory that allows the robot to pass next to the human without causing any discomfort. Note that as the robot does not immediately take a position behind the human, it avoids causing any discomfort when it is invisible to him.

The computed paths shown in Figures 11 and 12 are collision-free and also take into account the human's comfort and safety.

3. Conclusions

Results from the two HRI trials indicate that a large majority of human subjects, when seated, preferred a robot to approach from either the left or right side. The frontal approach was seen as uncomfortable, impractical, in some cases even threatening or confrontational, and should thus be avoided. This result is in line with human-human situations where standing or sitting at an angle of 45 degrees to each other can reduce feelings of aggression and confrontation [14]. However, the side that an individual human will actually prefer, left or right, depends to a large extent on the preferences of the individual concerned. The results do show that there is a bias towards the right hand side. This may be related to the fact that most of the trial subjects were right handed (in common with most of the population in general). Therefore, for a robot which is bringing an object to a seated human whose preferences are not known, it should always avoid a frontal approach and if (physically) convenient and consistent with the particular task then approach from the right. If the seated humans' approach direction preferences are known, then the robot should approach from the preferred direction whenever convenient[2]. It should be noted here that a human subject will not be unduly disturbed if their approach preference with regard to which side are not followed.

There were some perceived gender differences with regard to approach direction, with some females actually preferring a frontal approach direction, whereas slightly more males than females preferred a right side approach over other directions. From psychological studies [14] it has been found that women tend to stand slightly closer to one another, face each other more, and touch each other more, compared to men interacting with other men. That women tend to face each other more could possibly account for the fact that women in our studies more frequently preferred the robot to approach from the frontal direction compared to men, although this issue needs further investigation.

In the follow-up trials, no subjects thought that the robot came too close from either the right or left side directions, though a majority thought the front approach distance was too close. In all cases the robot approached to no closer than 50cm, which was the inbuilt safety collision avoidance distance of the robot. It has been noted that there are cultural differences in personal spatial zones [14][3]. However, although some subjects in the HRI trials may have originated from other countries and cultures, all the subjects had been resident in the UK and therefore could be presumed to adopt human-human social distances similar to those of the average UK population. Therefore, regional, cultural or ethnic origin information was not asked (or controlled) for in the studies[4].

Most subjects stated that the robot moved too slowly or about right at 0.4m/s, while nobody rated that the robot moved too fast. This suggests that (especially after a longer habituation period), most subjects would prefer the robot to move at a faster speed. It would therefore be reasonable to set the default robot speed at a relatively slow 0.4m/s and then perhaps increase the approach speed over time or in response to the user's wishes or preferences.

The robot used in the trials only had a simple short reach gripper, so the object was presented to the subject in a simple lifting tray. If a longer manipulator or arm was fitted, the results obtained may well be very different. It is desirable to perform further trials with various robots fitted with various types of arms or manipulators to see what effect they may have on user preferences. Also, long term trials are needed to investigate the effect on people of longer periods of exposure to robots. It would also be interesting to perform human-human studies to complement the work presented here. However, the primary focus of this paper is on robot to human approach direction preferences.

The human-aware motion planner is in its first steps of development and implementation. It requires further experiments to customize and validate the planner for live HRI situations. We are planning to implement this motion planner along with task reasoning capabilities [3] into a real robot that must have sufficient

[2] Deriving such 'social rules' for robots from empirical HRI studies is part of an attempt to develop a *robotic etiquette*, cf. B. Ogden, K. Dautenhahn (2000) Robotic Etiquette: Structured Interaction in Humans and Robots, in Proc SIRS2000, 8th Symposium on Intelligent Robotic Systems, The University of Reading, England, 18-20 July 2000.

[3] For example, many southern Europeans and Japanese have an intimate distance (reserved for close friends and family) of only 20-30cm compared to 46-122cm of the Americans and northern Europeans. Europeans might refer to Asians as 'pushy' and 'familiar' and Asians might refer to Europeans and Americans as 'cold' and 'stand-offish'. There are also differences in rural vs. urban spatial zones. People raised in more rural, less populated areas need more personal space, than those raised in densely populated cities.

[4] A specific study which investigates in more detail human robot approach distances using PeopleBot™ robots is given in Walters et al. [20].

human perception capabilities such as determination and tracking of various features like human-body posture, head orientation, hand configuration and gaze direction. In the execution stage of the plan, the robot must be highly reactive to changes in the environment. Using path deformation approaches can ensure this reactivity.

Joint work as described in this paper will ultimately contribute to the development of *interaction-aware robots* [5], i.e. robots that are sensitive to the social context they are embedded in. This is a vital requirement for all those robotics applications where human contact and acceptability plays a vital part, as it is the case in domestic, healthcare and other applications. The challenge to develop robots that are not only ‘doing the right thing’, but ‘doing the thing right’ [15] can only be tackled in a interdisciplinary endeavour involving psychologist as well as roboticists and HRI experts.

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