Embodied social interaction for robots

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Abstract

A key aspect of service robotics for everyday use is the motion of systems in close proximity to humans. It is here essential that the robot exhibits a behaviour that signals safe motion and awareness of the other actors in its environment. To facilitate this there is a need to endow the system with facilities for detection and tracking of objects in the vicinity of the platform, and to design a control law that enables motion generation which is considered socially acceptable. We present a system for in-door navigation in which the rules of proxemics are used to define interaction strategies for the platform.

1 Introduction

Service robots are gradually entering our everyday life. Already now more than 1 000 000 vacuum cleaners are in use in houses around the world (Karlsson, 2004). We are also starting to see robots being deployed as hospital logistic aids such as those provided by FMC Technologies for transportation of meals and linen. Not to mention the AIBO dog type robots that are provided by Sony. Gradually we are starting to see service types robots for assistance to people in terms of everyday tasks such as mobility aid, pick-up of objects, etc. As part of operation in public spaces it is essential to endow the robots with facilities for safe navigation in the vicinity of people. Navigation entails here both the safe handling of obstacles, going to specific places, and maneuvering around people present in the work area. For the interaction with human we see at least two modes of interaction: i) instruction of the robot to perform specific tasks incl. generation of feedback during the command dialogue, and ii) the embodied interaction in terms of motion of the robot. The embodied (non-verbal) interaction is essential to the perception of safety when the robot moves through the environment. The speed of travel that is considered safe very much depends upon the navigation strategy of the overall system.

Several studies of interaction with people have been reported in the literature. Nakauchi and Simmons (2000) report on a system for entering a line for a conference in which there is a close proximity to other users. Here the robot has to determine the end of the line and align with other users. Althaus et al. (2004) report on a system in which group dynamics is studied so as to form natural distances to other people in a group during in formal discussions. The control involves entering and exiting the group and alignment with other actors in the group. Passage of people in a hallway has been reported in Yoda and Shiota (1996, 1997). However few of these studies have included a directly analysis of the social aspects. They have primarily considered the overall control design.

In the present paper we study the problem of physical interaction between a robot and people during casual encounters in office settings. The encounters are with people that are assumed to have little or no direct model of the robots actions, and the interaction is consequently assumed to be with naive users. The encounters are in terms of meeting and passing robots that operate in room or corridor settings. Similar studies have been performed with users in professional environments such as hospitals, but we are unfortunately unable to report on the results of these studies.

The paper is organised with an initial discussion of social interaction during passage and person-person interaction in an informal setting in Section 2. Based on these considerations a strategy for robot control is defined in Section 3. To enable the study of behaviours in real settings a system has been implemented which allows us to study the system. The implementation is presented in Section 4. Early results on the evaluation of the system are presented in Section 5. These early results allow us to identify a number of issues that require further study. A discussion of these challenges is presented in Section 6.

Finally a number of conclusions and option issues are provided in Section 7.

2 Physical Passage 101

The spatial interaction between people has been widely studied in particular in psychology. The studies go back several centuries, but in terms of formal modelling one of the most widely studies models is the one presented in Hall (1966) which is frequently termed *proxemics*. The literature on proxemics is abundant and good overviews can be found in Aiello (1987) and Burgoon et al. (1989). The basic idea in proxemics is to divide space around the person into four categories:

Intimate: This ranges up to 30 cm from the body and interaction within this space might include physical contact. The interaction is either directly physical such as embracing or private interaction such as whispering.

Personal: The space is typically 30-100 cm and is used for friendly interaction with family and for highly organised interaction such as waiting in line.

Social: the range of interaction is here about 100-300 cm and is used for general communication with business associated, and as a separation distance in public spaces such as beaches, bus stops, shopping, etc.

Public: The public space is beyond 300 cm and is used for no interaction or in places with general interaction such as the distance between an audience and a speaker.

It is important to realize that the personal spaces vary significantly with cultural and ethnic background. As an example in in Saudi Arabia and Japan the spatial distances are much smaller, while countries such as USA and the Netherlands have significant distances that are expected to be respected in person-person interaction.

Naturally one would expect that a robot should obey similar spatial relations. In addition there is a need to consider the dynamics of interaction. The passage and movement around a person also depends on the speed of motion and the signaling of intentions, as is needed in the passage of a person in a hallway. As an example when moving frontally towards a robot one would expect the robot to move to the side earlier, where as a side-side relation is safer, due to the kinematic constraints. Consequently one would expect the proxemics relations can be modelled as elliptic areas around a person zones as shown in Figure 1.

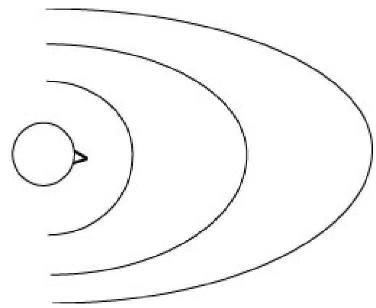

Figure 1: The interaction zones for people moving through a corridor setting

Video studies of humans in hallways seem to indicate that such a model for our spatial proxemics might be correct (Chen et al., 2004). One should of course here point out that the direction of passage also is an important factor. The "patterns of motion" is tied to social patterns of traffic in general. I.e. in Japan, UK, Australia, . . . the passage is to the left, while in most other countries it is to the right of the objects in a hallway. The general motion of people is closely tied to these patterns.

3 Design of a control strategy

Given that proxemics plays an important role in person-person interaction, it is of interest to study if similar rules apply for interaction with robots operating in public spaces. To enable a study of this a number of basic rules have been defined. The operation of a robot in a hallway scenario is presented here. Informally one would expect a robot to give way to a person when an encounter is detected. Normal human walking speed is 1-2 m/s which implies that the avoidance must be initiated early enough to signal that it will give way the person. In the event of significant clutter one would expect the robot to move to the side of hallway and stop until the person(s) have passed, so as to give way. To accommodate this one would expect a behaviour that follows the rules of:

1. upon entering the social space of the person initiative a move to the right (wrt to the persons reference frame).
2. move far enough to the right so as not to enter into the personal space of the person while passing the person.

3. await a return to normal navigation until the person has passed by. A too early return to normal navigation might introduce uncertainty in the interaction.

Using the rules of proxemics outlined in Section 2. One would expect the robot to initiate avoidance when the distance is about 3 meters to the person. The avoidance behaviour is subject to the spatial layout of environment. If the layout is too narrow to enable passage outside of the personal space of the user (i.e. with a separation of at least 1 meter) the robot should park at the side of the hallway. The strategy is relatively simple but at the same time it obeys the basic rules of proxemics.

4 Implementation of a passage system

To test the basic rule based design presented in Section 3 a prototype system has been implemented. The system was implemented on a Performance PeopleBot with an on-board SICK laser scanner, as shown in Figure 2. The system was designed to operate in the hallways of our institute which are about 2 meters wide, so the hallways are relatively narrow. To evaluate the system there is a need to equip the system with methods for

Figure 2: The PeopleBot system used in our studies

- Detection and tracking of people.
- Navigation in narrow spaces with significant clutter
- Path planning with dynamically changing targets to circumvent people and other major obstacles.

Each of the methods are briefly outlined below.

4.1 Detection of people

The detection of people is based on use of the laser scanner and the on-board sonar sensors. The laser scanner is mounted about 20 cm above the floor. This implies that the robot will either detect the two legs of the person or a single skirt. To allow detection of people scan alignment is performed Gutmann and Schlegel (1996) which enable differencing of scans and detection of motion. The scan differencing is adequate for detection of small moving objects such as legs (Nakauchi and Simmons, 2000). Using a first order motion model it is possible to estimate the joint motion of the legs or the overall motion of a single region (the skirt). Tracking is complicated by partial occlusions and significant motion of legs, but the accuracy of the tracking is only required to have an accuracy of ± 10 cm to enable operation. The tracker is operating at a speed of 6Hz, which implies that the motion might be upto 30 cm between scans. The ambiguity is resolved using the first order motion model in combination with fixed size validation gates (Bar-Shalom and Fortmann, 1987). The detection function generates output in terms of the position of the centroid of the closest person. In the event of more complex situations such as the presence of multiple persons a particle filter can be used as for example presented by Schulz et al. (2001).

4.2 Rules of interaction

The basic navigation of the system is controller by a trajectory following algorithms that drives the system towards an externally defined goal point. During interaction with a person the following strategy is used:

- Determine if there is space available for a right passage (given knowledge of the corridor provided by the localisation system)
- If passage is possible define a temporary goal point about 1 meter ahead and 1 meter to the right with respect to present position. Initiate a local mapper using laser data and sonar for navigation using a Nearness diagram method (Minguez and Montano, 2004).
- Upon entering an area ± 10 cm of the temporary goal point, define a new intermediate goal point that is next to the present person position but 1 meter beside the person, continue to the intermediate goal point using the nearness diagram method.
- Upon passage of the person resume the navigation task

- If no passage is possible park the robot close the right most most wall and resume navigation task once the person(s) have passed down the hallway.

4.3 The implemented system

The methods outlined above have been implemented on the PeopleBot (minnie) in our laboratory. The system uses an on board Linux computer and the control interface is achieved using the Player/Stage system (Vaughan et al., 2003) for interfacing. The SICK laser scanner and the sonar system is fed into a local mapping system for obstacle avoidance. In addition the laser scanner is fed into a person detection / tracking system. The output from the mapping system is used by the nearness diagramme based trajectory follower that ensures safe passage through cluttered environments. All the software runs in real-time at a rate of 6Hz. The main bottleneck in the system is the serial line interface to the SICK scanner.

5 Early evaluation

The system has been evaluated in real and simulated settings. The tests in real settings have involved both hallway environments and open spaces such as a department kitchen or large living room. To illustrate the operation of the system a single run is presented here.

In figure 3 is shown a setup in which the robot (blue trajectory) is driving down a hallway. The robot is about 3 m away from the person and is thus entering the social space of the approaching person.

At this point in time the robot selects a point to the right of the person and initiates an avoid maneuver. The turn is abrupt to clearly signal that it is give way to the person. The trajectory is shown in Figure 4. The red cross clearly marks the temporary goal of the robot.

As the robot reaches the passage trajectory it continues past the user (actually the user disappears from the view of the sensor). As is shown in Figure 5.

Upon completion of the passage behaviour the robot resumes its original trajectory which is the reason for the sharp turn towards it final destination, as shown in Figure 6

The results presented here are preliminary and to fully appreciate the behaviour of the robot for operation in public spaces there is a need to perform a user study to determine the value of such a behaviour. It is here also of interest to study how velocity of motion and variations in the distance will be perceived by

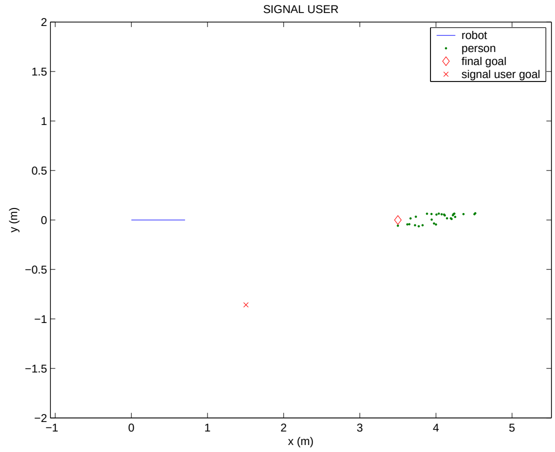

Figure 3: The initial detection of an encounter. The robot is driving towards the diamond marker when it detects a person moving in the opposite direction.An intermediate goal is defined that allows the robot to steer to the right

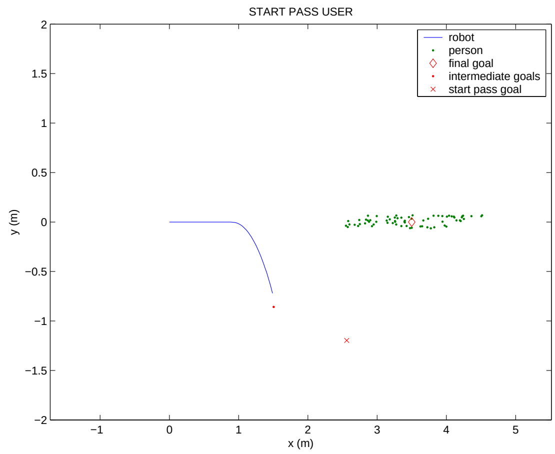

Figure 4: The initial avoid trajectory of the robot as it signals that it is giving way to the approaching person

people that encounter the robot. Such studies must be performed before any final conclusions on the study can be given.

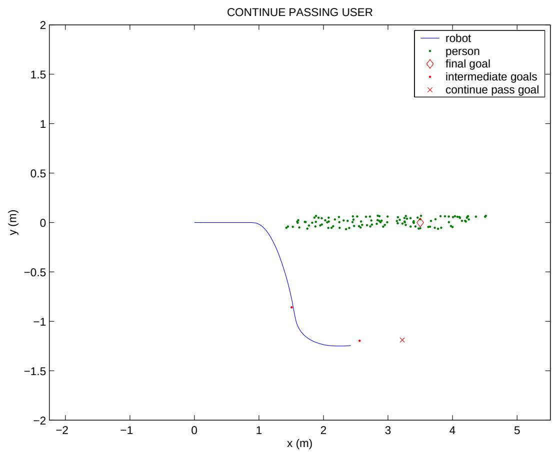

Figure 5: The pasage of the person is continued until the person disappears from the field of view of the sensor

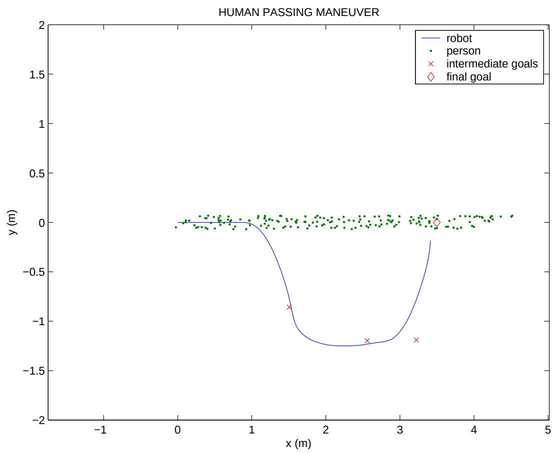

Figure 6: The completion of the passage behaviour

6 Challenges in embodied interaction

The design of a passage behaviour is merely one of several behaviours that are required in the design of system that operates in public spaces and interacts with naive users. The motion of the robot is crucial to the perception of the system. Simple jerky motion results in a perception of instability, and smoothness is thus an important factor. For operation in daily life situations there is further a need to consider the direct interaction with people so as to receive instructions from a user. As part of such actions there is a need to consider other social skills such as

- How to approach a person in a manner that signals initiation of a dialogue?
- If following a person, how fast can you approach a person from behind before it is considered tail gating?
- When entering into a group how is the group structure broken to enable entry?
- In a tour scenario where a person directs the person around, the robot is required to follow at a certain distance after the user, but when receiving instructions there might be a need to face the user to interpret gestures and for use of speech to receive instructions. How can both be achieved in a manner that is respectful and at the same time not too slow?
- In office buildings there might be a need to utilize elevators to enable access to multiple floors. How is the robot to behave for entering and exiting the elevator? Often elevators are crammed spaces and there is limited room to allow correct behaviour. If the robot is too polite it might never be admitted to an elevator in which there are people present. Many robots have a front and as such are required to enter the elevator and turn around, which in itself poses a challenge in terms of navigation. How does one signal intent to enter an elevator without being considered rude?

The embodied interaction with people is only now starting to be addressed and it is an important factor to consider in the design of a system, as both the physical design of the system and its motion behaviours are crucial to the acceptance of a final system by non-expert users.

7 Summary

As part of human robot interaction there is a need to consider the traditional modalities of interaction such as speech, gestures and haptics, but at the same time the embodied interaction, the body language of the robot, should also be taken in account. For operation in environments where users might not be familiar with robots this is particularly important as it in general will be assumed that it will behave in a manner similar to humans. The motion pattern of a robot must thus be augmented to include the rules of social interaction. Unfortunately many of such rules are not defined in a mathematically well-defined form, and thus is here a need for transfer these rules into control laws that can be implemented by a robot. In this paper the simple problem of passage of a person in a hallway has been studied and a strategy has been designed based on definitions borrowed from proxemics. The basic operation of a robot that utilizes these rules has been illustrated. The hallway passage behaviour is merely one of several different behaviours that robots must be endowed with for operation in spaces populated by people. To fully appreciate the value of such behaviours there is still a need for careful user studies to determine the utility of such behaviours and to fine-tune the behaviour to be socially acceptable.

Acknowledgements

This research has been sponsored by the Swedish Foundation for Strategic Research through its Centre for Autonomous Systems, the CEC as part of Cognitive Systems for Cognitive Assistants – CoSy. The financial support is gratefully acknowledged. The work has benefited from discussions with Prof. K Severinson-Eklundh, Ms. E. Topp, Mr. H. Hüttenrauch, and Mr. A. Green.

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