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Design of an Office-Guide Robot for Social Interaction Studies

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***Abstract*— In this paper, the design of an office-guide robot for social interaction studies is presented. We are interested in studying the impact of passage behaviours in casual encounters. While the system offers assistance in locating the appropriate office that a visitor wants to reach, it is expected to engage in a passing behaviour to allow free passage for other persons that it may encounter. Through use of such an approach it is possible to study the effect of social interaction in a situation that is much more natural than out-of-context user studies. The system has been tested in an early evaluation phase when it worked for almost 7 hours. A total of 64 interactions with people were registered and 13 passage behaviors were performed to conclude that this framework can be successfully used for the evaluation of passing behaviors in natural contexts of operation.**

I. Introduction

Robots are gradually entering into our daily life as part of logistical support in factories, for cleaning in supermarkets, and as part of professional service in offices and hospitals. When operating in these environments, the robots have to interact with persons as part of their normal operation. The interaction can be divided into a number of different classes: delivery of objects, receipt of instructions, and casual encounters. The direct interaction for delivery and instruction is typically performed by people that have direct knowledge of the robot operation and the interaction is usually controlled by the "user". With casual encounters we denote the operation in proximity of people that happen to be present in the work space of the robot. For such encounters it is considered important that the robot moves in a manner that instills confidence and provides the maximum consideration for people, while still trying to achieve mission objective(s).

In social studies the space around people has been divided into regions according to distance, termed proxemics [1]. Using these regions it is possible to design motion strategies for passage of people in such environments as corridor settings. Earlier work on this has been reported in [2], [3]. Studies of methods for passage of people in everyday environments are, however, difficult to perform outside of the context of a robots normal operation. There is a risk that such studies of passage, not embedded in a natural context of operation, may become artificial.

To study the impact of passage behaviours as part of normal robot operation, a system for visitor guidance in an office environment has been designed. The system is to detect the entry of a visitor to the environment, and offer assistance in locating the appropriate office / cubicle that the visitor is expected to go to. During its guidance to the destination office, other people in the environment might be encountered and the system is here expected to engage in the passage behaviour to allow free passage for the encountered person while it continues towards its destination. Over time the behaviour of the robot can be varied to study the long-term effects of different design choices. The objective is here to allow for studies of the impact of different design over extended periods, with users that are accustomed to interact with the robot. Through use of such an approach it is possible to study the effect of social interaction in a context that is much more natural than out-of-context user studies.

A variety of guidance robots have been reported in the literature including Xavier [4], RHINO [5], MINERVA [6], Nursebot [7] and RoboVie [8]. As part of the design of some of these robots the social interaction between the visitor and the robot has been studied, but to our knowledge the study of social interaction with other people in the environment has so far not been considered.

The paper is organized with a presentation of the overall design of the guidance robot with social interaction in Section II. The implementation considerations are discussed in Section III. The system has now been in operation for close to a month and early results with the system are reported in Section IV. Finally an outlook and a summary are provided in Section V.

II. Design of Office-Guide Robot

A system for visitor guidance in an office environment has been designed. Besides the interest in having an office-guide robot operating in our lab, such system is intended to provide a test bed for our studies on robot social passage behaviour. An office-guide functionality in fact, allows the robot to operate continuously and creates a natural context in which casual encounters with people can occur.

A. The Setting

The system has been designed to operate in the corridors of our lab, where the offices of researchers, students and staff personnel are located. The two corridors in our institute, on the 6th and the 7th floor, have similar layouts. In Figure 1 the layout of the 7th floor corridor is shown. The corridor is 33 m long and it consists of a main part (section A from 1.7 m to

2 m wide) and a narrower area (section B, 1.3 m wide) where the staircase that connects the two floors is located.

The task is for the system to wait for visitors in front of the elevator and offer assistance to go to any office on the floor. Upon completion of a guidance mission the robot should return to its home position by the elevator.

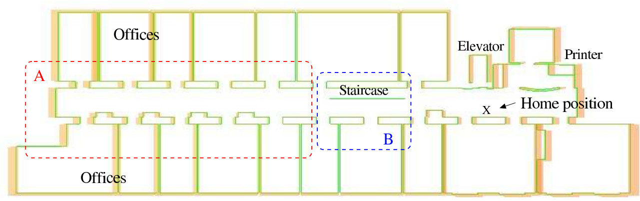


Fig. 1. The layout of the corridor where the office-guide robot operates. The robot goes back to the home position in front of the elevator after every mission.

B. Overall System Description

For the scenario outlined in Section II-A, the robot is parked outside the elevator. It monitors the elevator for people coming out of it using information from an on-board laser scanner. When the robot detects a person coming out of the elevator it addresses her/him and offers to provide assistance. The person is invited to indicate the desired location on an on-board touch-screen. If the person does not select a destination within some time, the robot goes back to look for people coming out of the elevator. If a destination is selected, the robot drives to the desired location guiding the person there. Figure 2 outlines the different states that the robot goes through during a mission. The diagram shows the transitions for a successful mission

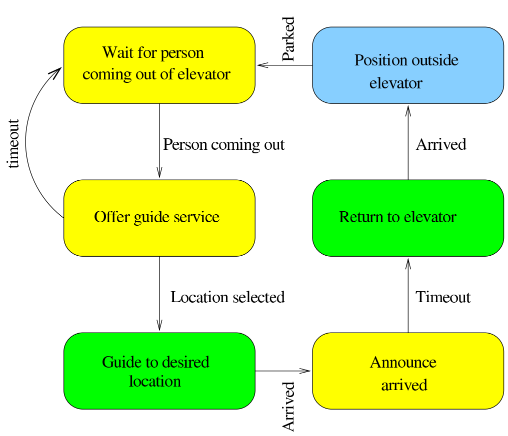


Fig. 2. The state transitions for the guide robot. The idle state is when the robot is waiting outside the elevator for people to arrive. If a person coming out of the elevator does not ask for its services, after a certain time the robot goes back to look for new people.

and excludes any details having to do with error handling. After the user has chosen a location, the robot uses speech to inform her/him that it is heading to that particular destination. When the destination has been reached, this is also announced through speech.

While traveling to and back from a destination the robot typically encounters other people and this is where the interactions we are interested in the paper occur.

Figure 3 gives an overview of the main components in the system. The user interface provides the system with the

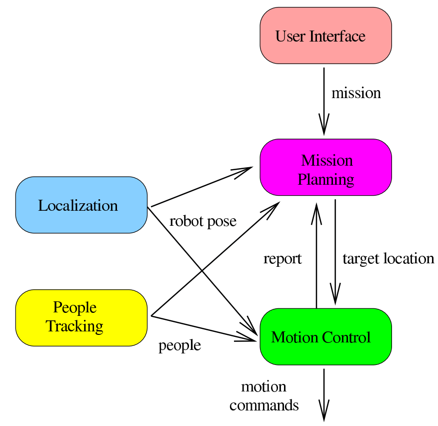


Fig. 3. The main components of the guide robot system. The focus in this paper is on the Motion Control module.

mission goal from the person that wants to be guided. The mission planning breaks this down into subtasks that are fed to the Motion Control module. In addition to the specification from the mission planner and sensor data, the Motion Control module also receives input from the localization system and a module that tracks people in the vicinity of the robot.

The main interest in this paper is on the Motion Control module (see Figure 4). As already pointed out, the purpose of

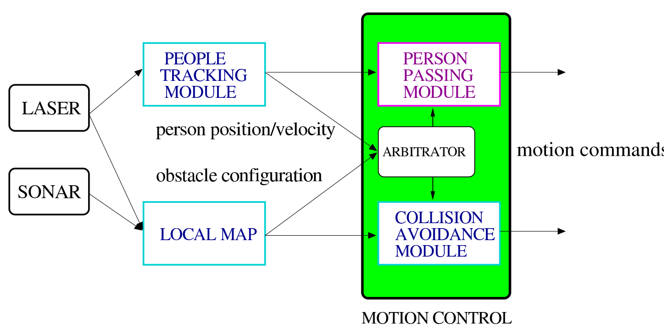


Fig. 4. The Motion Control module and its main components: Collision Avoidance module and Person Passing module.

the system is to provide a framework to study the nature of patterns of spatial interaction in casual encounters. Guidance is thus a secondary focus, as it (merely) provides an application context to allow the study of robot navigation among people. As described in more details in [2], the Motion Control module navigates the robot in presence of static and moving obstacles (persons). It consists of two main components: a standard collision avoidance module for safe navigation in dynamic and cluttered environments and a module that achieves the people passing behaviour (see Section II-C).

C. Person Passing Strategy

The Person Passing algorithm has been inspired by human spatial behaviour studies [9]. In particular the robot behaviour follows a number of basic rules:

1) upon entering the social space of the person initiate a move to the right (wrt. to the robot reference frame) to signal the person that has been detected.
2) move as far to the right as the layout of the corridor allows, if needed, while passing the person.
3) await a return to normal operation (e.g. navigation toward a goal) until the person has passed. A too early return to normal operation might introduce uncertainty in the interaction.
4) if there is not enough room on the right side to pass the person, the robot should move to the side of the corridor and stop until the person(s) have passed, so as to give way.

The last rule is particularly important not to block people's path when the robot is driving in the narrower areas of the corridor.

III. Implementation

The office-guide robot application has been implemented on "Minnie", the Performance PeopleBot platform shown in Figure 5. Minnie is equipped with a SICK laser scanner, sonar sensors, pan-tilt camera and bumpers. The system has an on-board Linux computer and uses the Player software (Vaughan et al. [10]) for interfacing the robot sensors and actuators.

Fig. 5. The Performance PeopleBot Minnie was used as the experimental platform.

A. Software Architecture Modules

The main components of the software architecture are:

1) People Tracking Module. The tracking module detects and tracks people in the environment and it is based on laser information; it provides information about the current position and velocity of people. The underlying motion detection algorithm is inspired by [11].
2) Person Passing Module. The Person Passing module has been designed to perform passage of a person, according to the previously defined proxemics rules.
3) Collision Avoidance Module. The Nearness Diagram (ND) method by Minguez and Montano [12] is used for the avoidance system as it is well suited for motion among very close obstacles, a situation that can occur in a narrow corridor.
4) Localization Module. The localization system is based on the same main components that were used in [13] and is part of the CURE/toolbox software[1].
5) GUI. The graphical interface is implemented in JAVA and presents the user with a list of offices/staff members. A touch screen allows the user to select a destination easily.
6) Speech Module. The speech functionality is achieved using the Festival speech synthesis system coupled to Player.

B. Person Passing Module

The Person Passing module operation has been described in details in [2] and can be summarized as follows: as soon as a person is detected in front of the robot, closer than a certain front distance d_F, the robot steers to the right to maintain a desired lateral distance d_L from the user. If there is not enough space, as might be the case for a narrow corridor, the robot is commanded to move as much as possible to the right to signal to the user that it has seen her/him and is moving out of the way to lets her/him pass. It is possible to define a "family" of passage behaviors through the tuning parameters d_F, d_L and the robot speed. A desired trajectory is determined, that depends on the relative position and speed of the person and the environment configuration encoded in the local map. The desired trajectory is computed via a cubic spline interpolation. The control points are the current robot configuration (x_0^R, y_0^R), the desired "passage" configuration (x_P^R, y_P^R), and the final goal configuration (x^G, y^G) in the corridor frame of reference, where the x axis is aligned with the main direction of the corridor (see Figure 6).

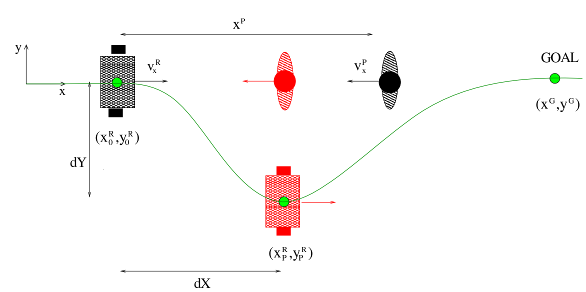


Fig. 6. Desired trajectory for the passage maneuver. The distance of the robot from the person is maximum when it is passing her/him (red).

Compared to the work in [2], rule 4 from II-C has been implemented and integrated in the algorithm. In the previous

[1]CURE stands for CAS Unified Robot Environment and the toolbox is a collection of tools to perform navigation, localization and mapping.

implementation the robot was forced to stop at its current position in every situation in which it was not allowed to pass the person:

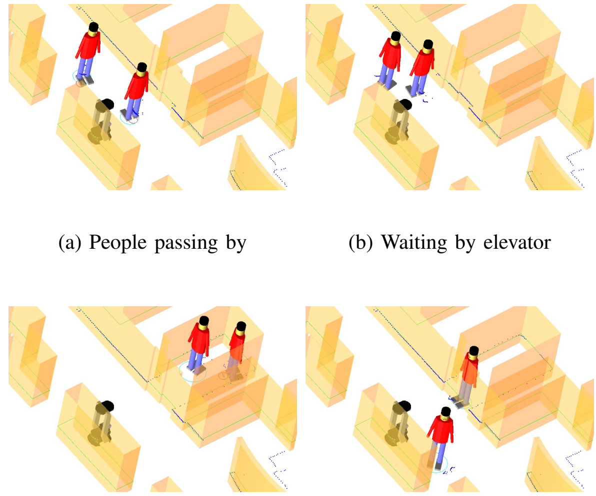
- there is not enough space to the right side of the robot to perform a Person Passing (PP) maneuver
- the person is on the "wrong" (right) side of the corridor
- the person is too close to perform a PP maneuver
- the final goal is too close to perform a PP maneuver

When the robot has no room to pass the person, it is not considered acceptable to attempt to perform a maneuver. This would result in a danger of collision for the robot and, more important, in a violation of the proxemics rules on which the robot's behaviour is based. In the current version the robot is not forced to stop on the spot in the above situations but a Park-To-the-Side (PTS) maneuver is performed instead, which steers the robot to the right side of the corridor and parks it there until the person has passed. The Park-To-the-Side feature is essential to allow the encountered people a smooth passage in the narrowest parts of the corridor. Especially for the purpose of this application – a long term study – to stop the robot at its current position would not have been acceptable. This may in fact results in having the robot stuck in the middle of the corridor blocking people's path, given the limited width of the corridor. The robot is forced to stop on the spot only when it gets too close to a person or to a static obstacle, as a safety measure.

IV. Early Experimental Evaluation

An experimental evaluation has been carried out to test the system. The experiments were performed in our working space (as shown in Figure 1). To be realistic the experiments were performed during normal working hours. Experimental validation has been performed over the last month to ensure robust operation. The motion detection module, in particular, successfully detects the arrival of people from the elevator, filtering out the persons that are just passing by or waiting for the elevator. Figure 7 shows four snapshots from the area outside the elevator where the robot is waiting to guide visitors to a location of the their choice. The laser data are shown, as blue dots superimposed on the map, together with the people's position from the People Tracking module. The robot looks for people coming out of the elevator and ignores those that are passing by or just waiting to leave the area.

The frequency of people arriving in our building is relatively low compared to the normal work cycles for robot batteries, which poses a challenge to the system. We are at present installing an automatic re-charge station at the home location to address this problem. Moreover when a visitor arrives and the robot is finally engaged in its office-guide task, the probability of an encounter with another person is low. Consequently extended periods of testing are needed to collect enough statistics for these studies. In order to gather enough data of passing interactions for an early evaluation of the system, a small modification was performed to initiate a guidance task directly through the GUI. This has generated a larger number of missions than it could have been possible if the robot had to wait for visitors to appear from the elevator. At the same time, the casual nature of the encounters was preserved since people were unaware of the purpose of the experiments and were leaving from and coming back to their offices on their own will. The experimental results reported below were collected over 3 days. The first 2 days the robot was located on the 7th floor. The third day the robot was moved on the 6th floor; the idea was to have the robot operating during the Friday coffee-break of the lab when everybody gather in the kitchen and the corridor is very busy with people.



(a) People passing by (b) Waiting by elevator

(c) Inside elevator (d) Coming out

Fig. 7. a) People passing by in the corridor outside of the elevator. b) People waiting to enter the elevator. c) People inside the elevator. d) People are coming out of the elevator and the robot asks if anyone needs guidance.

A. Experimental Results

Figure 8, 9 and 10 show an example of the robot operation during its guidance missions. The following values were used for the passage behaviour parameters: $d_F = 6.0\,\text{m}$, $d_L = 0.3\,\text{m}$, robot max speed = 0.5 m/s. The trajectories of the robot (from the Localization module) and the persons (from the People Tracking module) are shown.

In Figure 8, the robot has just performed a guidance mission to the office shown in the figure and is heading back to its home position in front of the elevator. During this new mission it encounters a person heading to his office first (person 1 in the figure) and then a second person in the staircase area (person 2). The robot performs a PP maneuver to pass the first person. It cannot pass the second person though and it parks to the side until the person has passed. The first part of the robot path (in ND mode) before the passing maneuver shows large turns; this is due to the fact that the algorithm reacts to the obstacles present on the right of the robot (the shelves in this case) but the size of the turns is emphasized by the figure's scale in which the x axis is much more compressed than the y axis. The same turns appear much smaller in Figure 9 which

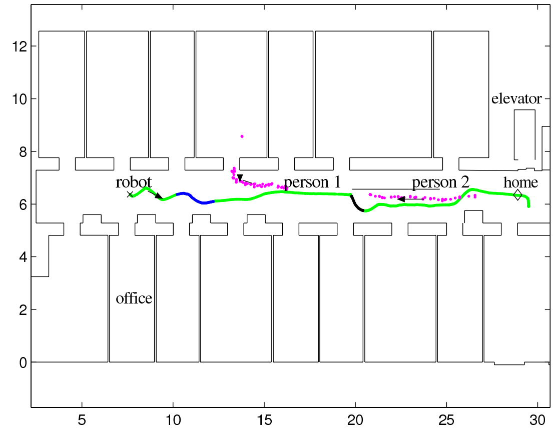


Fig. 8. Two casual encounters in the corridor. Person-Passing behavior and Park-To-the-Side behavior. The robot's and person's trajectories are shown: robot (green = ND mode, blue = PP mode, black = PTS mode) and person (magenta). The arrows indicate the direction of motion.

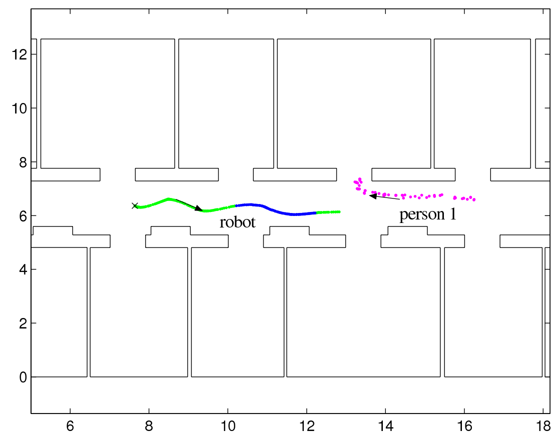


Fig. 9. Close-up on the Person Passing maneuver. The robot clearly turns to the right to signal the person that it has seen him and that it is letting him pass.

has an equal axis scale.

This figure presents a close up on the PP maneuver. It shows how the first person encountered leaves enough space to the robot to pass, so the passage maneuver is mostly meant to signal the person that the robot has perceived his presence and is letting him pass. The passage of the person is not completed because the person enters in his office.

Figure 10 presents a close up on the second encounter: the PTS maneuver allows the person to pass in spite of the narrow dimension of the corridor.

The statistics of the office-guide robot are summarized in Table I. The table shows the dates and locations of the experiments together with duration in time, travelled distance, number of missions performed, number of the interactions

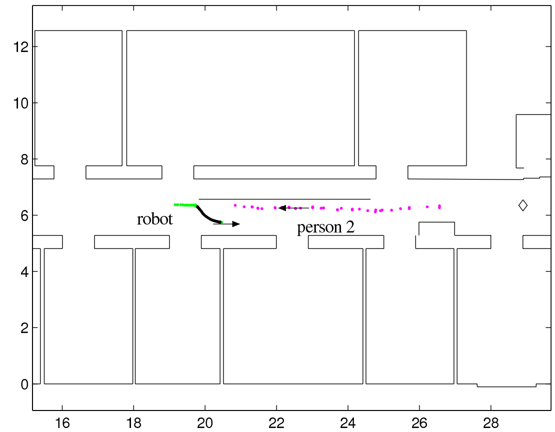


Fig. 10. Close-up on the Park-To-the-Side maneuver. The robot moves to the side and stops until the person has passed.

TABLE I

STATISTICS OF THE OFFICE-GUIDE ROBOT'S OPERATION.

Date	location	time	dist	missions	inter/PP
February 8	7th floor	2:02	1192 m	60	22/3
February 9	7th floor	1:56	1105 m	58	18/3
February 10	6th floor	2:45	1504 m	80	24/7
Total		6:43	3801 m	198	64/13

occurred and among them, the number of passing-interactions. As can be seen, about 1/3 of the missions resulted in a encounter with a person and consequently in an interaction. Additionally, it can be observed that in most of the recorded interactions the robot maneuver is a Park-To-the-Side one rather than a Person-Passing. The explanation of this low ratio may be twofold. On one hand, the staircase area of the corridor is very narrow and it is often quite crowded with people that need to access the printer location. Many PTS maneuvers were performed by the robot in this area. On the other hand, if the person does not leave enough room to the robot while passing, the PP maneuver cannot be performed even in the relatively wider part of the corridor. So many PTS maneuvers were recorded in the wider part too. Different attitudes have been observed among people, one of which is to walk straight ignoring the robot. In this case the robot may be forced to park to the side to let the person pass. Moving the robot from the 7th to the 6th floor has incremented the occurrences of the PP maneuvers. On Friday in fact people gather to the kitchen for the break and then go back to their office: most of the encounters happened in the wider part of the corridor.

The system worked for slightly less than 7 hours for a total of 198 missions accomplished. During the system's operation a total of 64 interactions were registered, most of them (51) were handled by the robot with a PTS maneuver which allowed the encountered people a smooth passage in the cramped areas of the corridor. A number of passage behaviors was also performed (13). The study of the interaction patterns in passing is of primary interest for the long-term study that the system is intended for, and it is expected that this implementation will allow the evaluation of passing behaviors in natural everyday situations.

The robustness has been verified for the main components: Localization, People Tracking and Collision Avoidance modules. The tracking system never failed to detect an incoming person. False detections of motions where noted though as a result of the offices sliding glass doors. The laser sometimes fails to detect the glass which creates an illusion of motion that has been accepted by the tracking module as a person in a few cases. This has resulted in a small number (2–3) of undue PTS or PP maneuvers.

When the Collision Avoidance module slows down the system in cluttered areas, the behaviour of the robot can be perceived as non intuitive for the people around. To limit the problem a speech output has been added to inform people when the robot is reducing its speed to enable safe passage of detected persons.

The batteries of the PeopleBot platform allows continuous operation of the robot for only an hour. In the current implementation the batteries were changed manually. But this short duration poses a challenge to the long term study in which the robot is supposed to stand in front of the elevator for an amount of time that can be long, waiting to offer its service to visitors. An autonomous docking capability for battery-recharging is therefore needed. Adaptation of an existing recharging station to the PeopleBot platform is part of on-going work.

In general it can be concluded that the performances of the system met the expectations. In spite of the above limitations the system is robust enough to allow a smooth and continuous operation for the long-term experimentation that is intended to be performed.

V. Summary and Outlook

To study the impact of passage behaviours as part of normal robot operation, a system for visitor guidance in an office environment has been designed. While the system offers assistance in locating the appropriate office that a visitor wants to reach, it is expected to engage in a passing behaviour to allow free passage for other persons that it may encounter.

Through use of such an approach it is possible to study the effect of social interaction in a situation that is much more natural than out-of-context user studies. Moreover, the proposed framework will allow us to vary the behaviour of the robot over time, selecting different settings of parameters, to study the long-term effects of different design choices.

The system has been tested in an early evaluation phase when it operated for almost 7 hours. A total of 64 interactions were registered, most of them (51) were handled with a Park-To-the-Side maneuver which allowed to the encountered people a smooth passage in the most cluttered parts of the corridor. Several passage behaviors were also performed (13) to conclude that this framework can be successfully used for the evaluation of passing behaviors in casual encounters.

The frequency of interactions in a natural environment is relatively low, say 5 missions per day, which challenges the present battery performance. An automatic re-charge functionality has been prepared and a long-term study is currently going on that will allow us to achieve insight on social interaction and, more in general, on the long-term effects of deployment of robotics in our normal work environment.

Acknowledgment

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