Embodied Social Interaction for Service Robots in Hallway Environments

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Summary. A key aspect of service robotics for everyday use is the motion in close proximity to humans. It is essential that the robot exhibits a behavior that signals safety of motion and awareness of the persons in the environment. To achieve this, there is a need to define control strategies that are perceived as socially acceptable by users that are not familiar with robots. In this paper a system for navigation in a hallway is presented, in which the rules of proxemics are used to define the interaction strategies. The experimental results show the contribution to the establishment of effective spatial interaction patterns between the robot and a person.

Keywords: Service robotics, hallway navigation, robot-human interaction, embodied social interaction.

1 Introduction

Robots are gradually entering our daily lives to take over chores that we would like to be without and for assistance to elderly and handicapped. Already today we have more than 1.000.000 robots in domestic use (Karlsson, 2004). In terms of (semi-) professional use we are also starting to see robots as courier services, and as part of flexible AGV-systems.

As robots start to enter into daily lives either in homes or as part of our office/factory environment, there is a need to endow the robots with basic social skills. The robot operation must of course be safe, but in addition we expect the robot to interact with people following certain social rules. An example of this is passage of people when encountered in the environment. When people pass each other in a corridor or on the factory floor, certain rules of encounter are obeyed. It is natural to expect that robots, at least, should follow similar rules. This is in particular important when robots interact with users that are inexperienced or have never before met a robot.

Several studies of physical interaction with people have been reported in the literature. Nakauchi & Simmons (2000) report on a system that is to stand

P. Corke and S. Sukkarieh (Eds.): Field and Service Robotics, STAR 25, pp. 293–304, 2006.

in line for event registration. Here the robot has to detect the end of the line and position itself so as to obey to normal queueing behavior. Althaus et al. (2004) report on a system that is to participate in multi-person interaction as part of a group. It is here important to maintain a suitable distance from the other actors and to form a natural part of the group. Passage of people in a hallway has been reported by Yoda & Shiota (1997); an avoidance algorithm has been developed, based on a human avoidance model, where two separate conditions of a standing and walking person were considered.

In this paper we study the problem of social interaction of a robot with people in a hallway setting and present an algorithm for person passage that, in contrast with the one proposed by Yoda & Shiota (1997), dynamically adapts the robot's behavior to the person's motion patterns. A overall description of the spatial interaction among people during passage is presented in Section 2, and the corresponding control strategy for the robot is presented in Section 3. The implementation of the proposed strategy is described in Section 4. The system has been evaluated in a number of different tests to show its handling of standing and moving people and the corresponding handling of regular obstacles. The experimental results are summarized in Section 5. Finally the main observations, open questions and issues for future research are presented in Section 6.

2 Human Spatial Interaction

Interaction between people has been widely studied both as part of behavioral studies and in psychology. Formal models of interaction go back to the 1960s when one of the most popular models in the literature, the *proxemics* framework, was presented by Hall (1966). The literature on proxemics is rich, but good overviews have been presented by Aiello (1987) and Burgoon et al. (1989). In proxemics the space around a person is divided into 4 categories:

Intimate: This ranges up to 45 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 45-120 cm and is used for friendly interaction with family and for highly organized interaction such as waiting in line.

Social: The range of interaction is here about 1.2-3.5 m 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 3.5 m 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 space varies significantly with cultural and ethnic background. As an example in Saudi Arabia and Japan the spatial distances to be respected in person-person interaction are much smaller, than in countries such as the USA and the Netherlands. The passage/encounter among people does not only depend upon the interpersonal distance, but also the relative direction of motion. At the same time there are social conventions of passage that largely follow the patterns of traffic. So while in Japan, UK, Australia, ... the passage in a hallway is to the left of the objects, in most other countries it is to the right.

One could model the personal space for a human as a set of elliptic regions around a person as shown in Figure 1. Video studies of humans in hallways seem to indicate that such a model for our spatial proxemics might be correct Chen et al. (2004).

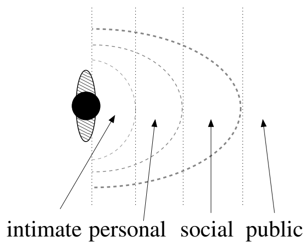

Fig. 1. The interaction zones for people moving through a hallway setting

It would be natural to assume that the robot respects the same physical boundaries as we expect from other people, if the robot has to display some level of "social intelligence".

3 The Control Strategy

The operation of a robot in a hallway scenario is presented here. Given that proxemics plays an important role in person-person interaction, it is of interest to study if similar rules apply for the interaction between people and robots operating in public spaces. 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 the robot has detected the presence of a person and to indicate its intention to provide safe passage for her/him. In the event of significant clutter the robot should move to the side of the hallway and stop until the person(s) have passed, so as to give way. A number of basic rules for the robot behavior may thus be defined:

1. Upon entering the social space of the person initiative a move to the right (wrt. to the robot reference frame) to signal the person that has been detected.
2. Move to the right to respect a desired distance from the person (if the layout of the hallway allows) 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 discomfort on the user's side.

Using the rules of proxemics outlined in Section 2, one would expect the robot to initiate avoidance when the distance is about 3.5 m to the person. Given a need for reliable detection, limited dynamics and early warning however, a longer distance for reaction was chosen (6 m). The avoidance behavior 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, as in the case of a corridor, it is considered sufficient for the robot to move to the right as much as it is possible, respecting a safety distance from the walls. The strategy is relatively simple but at the same time it obeys the basic rules of proxemics.

4 An Implementation

The strategies outlined above have been implemented on a Performance PeopleBot from ActivMedia Robotics (Minnie). Minnie is equipped with a SICK laser scanner, sonar sensors and bumpers (see Figure 2).

Fig. 2. The PeopleBot system

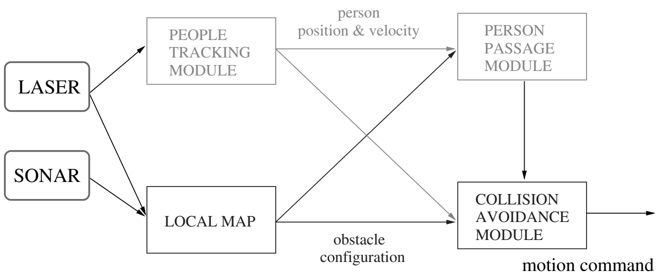

Fig. 3. The overall control system architecture

The system on-board computer runs Linux and uses the Player software (Vaughan et al., 2003) for interfacing the robot sensors and actuators. The main components of the control system are shown in Figure 3.

The laser and sonar data are fed into a local mapping system for obstacle avoidance. In addition the laser scans are fed into a person detection/tracking system. All the software runs in real-time at a rate of 10 Hz. The serial line interface to the SICK scanner runs at a rate of 5 Hz.

The tracking module detects and tracks people in the environment; the laser is mounted on the robot at a height of 33 cm from the ground to perform leg detection of the persons. Information about the current position of the people as well as their velocity is provided. Both the magnitude and the direction of the velocity are important to decide when and how to react. A particle filter, as the one presented by Schulz et al. (2001), is used which can deal with the presence of multiple persons.

The navigation system relies on a local mapper that maintains a list of the closest obstacle points around the robot. Obstacle points are pruned away from the map when they are too far from the robot or when there is a closer obstacle in the same direction. The sonar data are processed through the HIMM algorithm by Borenstein & Koren (1991) before being added to the map. The collision avoidance module can deal with significant amount of clutter but it does not take the motion of the obstacles into account as part of its planning and it does not obey the rules of social interaction. The Nearness Diagrams (ND) method by Minguez & Montano (2004) has been chosen because it is well suited for cluttered environments. The Person Passage module (PP) implements a method for navigating among dynamically changing targets and it is outlined in the next Section. During normal operation the robot drives safely along the corridor toward an externally defined goal. The goal is feed to the collision avoidance module. In parallel the person tracker runs to detect the potential appearance of a person. If a person is detected by the people tracker both the PP and the ND modules are notified. The PP module generates a strategy to pass the person. If, due to the limited width of the corridor the passage would involve entering into the personal space of the person, the ND module will override the generate motion commands and park the vehicle close the wall of the hallway, until the person has passed. Otherwise the generated motion commands are filtered through to the robot.

It is important to underline here some important assumptions that have been made in the implementation. The approach consider the presence of one person at a time; to deal with the simultaneous presence of multiple persons this strategy should be extended. It is assumed that the robot operates in a hallway wide enough to allow the simultaneous passage of the robot and the person; this means that the only impediment to the robot's maneuver is represented by the person behavior (i.e. the person's pattern of motion along the corridor). The presented method aims at achieving a low level control modality whose only competence is to determine a passage maneuver on the right of the person, when it is possible, or to stop the robot otherwise. We believe that it is crucial to stick to this simple set of rules to avoid any ambiguity in the robot behavior. In situations where the method decides to stop the robot, a high level module based on a more complete set of information (localisation of the robot on a global map of the environment, user motion model for person's behavior prediction) could determine alternative motion patterns for the robot.

4.1 Person Passage Method

The Person Passage module has been designed to perform a passage maneuver of a person, according to the previously defined proxemics rules. It operates as follows: as soon as a person is detected at a frontal distance below 6 m, the robot is steered to the right to maintain a desired lateral distance from the 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 to the right to signal to the user that it has seen her/him and lets her/him pass.

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), where x is in the direction of the corridor (see Figure 4).

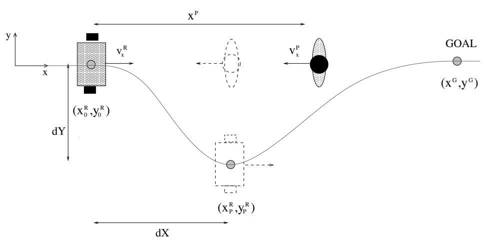

Fig. 4. Desired trajectory for the passage maneuver. The distance of the robot from the person is maximum when it is passing her/him (*dashed line*)

The control point (x_P^R, y_P^R) determines the passage maneuver, and is computed as follows:

$$x_P^R = x_0^R + dX \tag{1}$$

$$y_P^R = y_0^R + dY \tag{2}$$

The value of dY depends on the lateral distance LD that the robot has to keep from the person:

$$dY = LD + w_R/2 - (y^P - y_0^R) \tag{3}$$

where w_R is the robot's width and y^P is the person's y coordinate in the corridor frame. The value of dY may be limited by the free space on the robot right. dX is computed so that the robot maintains the maximum distance from the person when it is passing her/him, according to 4:

$$dX = v_x^R/(v_x^R - v_x^P) \times (x^P - x_0^R) \tag{4}$$

The robot starts the maneuver by clearly turning to the right to signal to the person its intent to pass on the right side, then the maneuver is updated according to the person's current relative position x^P and velocity v_x^P (see 4), until the person has been completely passed, at which point the robot returns to its original path. The capability to adapt to the changes in the speed of the person is crucial to establish a dynamic interaction between robot and person, as will be shown in Section 5, and represents an important improvement with respect to the work of Yoda & Shiota (1997).

The adopted trajectory following controller takes into account the differential drive kinematics of our robot to define the feed forward command (driving and steering velocity) (Oriolo et al., 2002):

$$v_D(t) = \sqrt{\dot{x_d}^2(t) + \dot{y_d}^2(t)} \tag{5}$$

$$v_S(t) = \frac{\ddot{y_d}(t)\dot{x_d}(t) - \ddot{x_d}(t)\dot{y_d}(t)}{\dot{x_d}^2(t) + \dot{y_d}^2(t)} \tag{6}$$

where $x_d(t)$ and $y_d(t)$ is the reference trajectory. The controller includes also an error feedback in terms of a proportional and a derivative term.

5 Experimental Results

The system has been evaluated in a number of different situations in the corridors of our institute, which are relatively narrow (2 m wide or less). During the experiments the "test-person" was walking at normal speed, that is around 1 m/s; the average speed of the robot was around 0.6 m/s.

5.1 Person Passage

The experiments show how the system performs in the person passage behavior, adapting to the person speed and direction of motion. Three different cases are here presented.

In the first situation a person is walking at constant speed along the corridor. Figure 5 depicts top-down four different steps of the encounter. The robot starts its course in ND mode. As soon as the robot detects the person at a front distance below 6 m, it starts its maneuver with a turn toward the right (first snapshot). This makes the person feel more comfortable and most people will instinctively move to the right too, to prepare for the passage, as it happens in the second snapshot. As soon as the person has been passed by the robot, the robot resumes its path along the center of the corridor (third and fourth frames). The steering maneuver of the robot results in an effective interaction with the user; to achieve this result, it has been crucial to perform a clear maneuver with a large advance. In the second test (see Figure 6), the person walks along the corridor and then stops. The robot starts its maneuver at the same front distance from the person as before (first frame) but then, detecting that the person has stopped (second frame) it does not turn

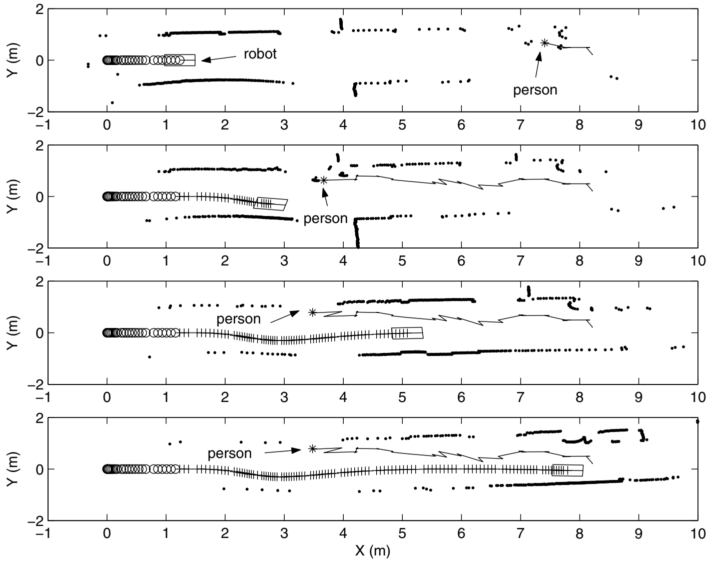

Fig. 5. A person walks along the corridor. The robot trajectory in ND (*circle*) and in PP mode (*plus*) is represented. The person trajectory (*continuous line*) and current position (*star*) together with the current obstacle points on the local map (*dots*) are also shown. The robot steers to the right to pass the person and then resumes its course

toward the center of the corridor but it continues on the right until it has completely passed the person (third frame). Then the robot resumes its path toward the goal (fourth frame). Updating on-line the desired trajectory has allowed the robot to adapt the passage maneuver to the person relative position and velocity. This is a key feature to establish an interaction with the person that perceives the robot operation as safe and "social". In the third test (see Figure 7), the person is walking along the corridor and then turns to his left to enter in his office. The robot starts a maneuver of passage as before (first and second frames) but then, as soon as it detects the person on the "wrong" side of the corridor, it stops (third frame). Once the person is not detected any more, the robot resumes its path in ND mode (fourth frame). In this situation, the environment layout does not allow the robot to pass the person on the right and a passing maneuver on the left would be perceived by the person as not natural and unsafe, contradicting the social conventions of spatial behavior. In such a situation, it is considered as the best solution for the robot to stop.

5.2 Regular Obstacles Handling

This second set of experiments show how the robot handles regular objects in the environment. A paper bin was placed in the corridor, in the robot path.

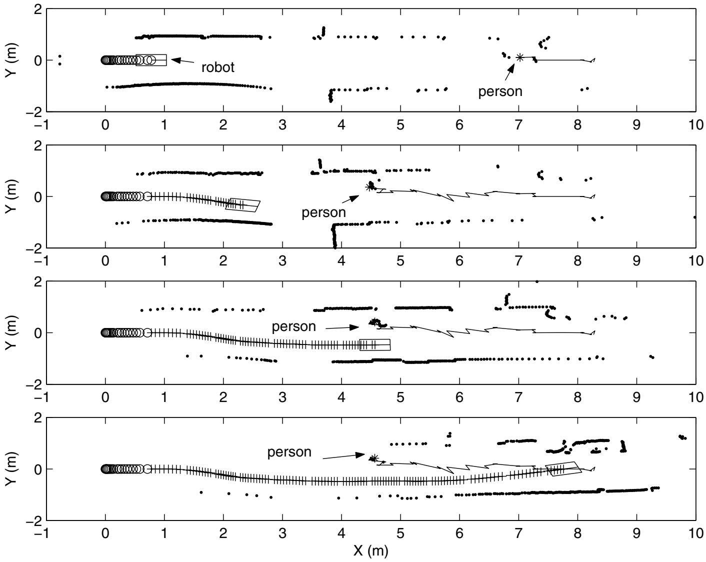

Fig. 6. The person stops. The robot waits until it has passed the person to resume its course on the center of the corridor

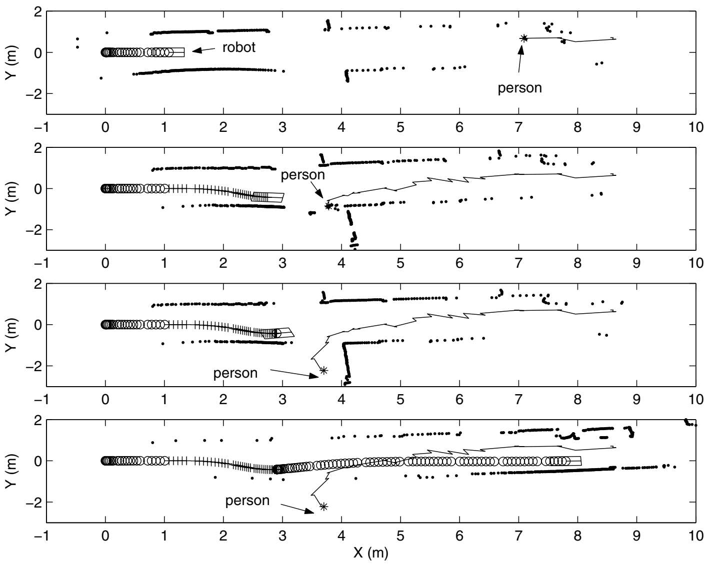

Fig. 7. The person crosses the robot path. The robots stops and wait until the person has disappeared from the field of view of the laser to resume its path in ND mode

The controller was in ND mode with a security distance of 0.6 m, because no persons were around. Two different configurations of the paper bin with respect to the corridor have been considered. In the first situation the bin is on the left of the hallway, close to the wall. The robot circumvents it on the right (see Figure 8, left). This is automatically achieved with the ND because the right is the only free direction). It is important to observe here that ND drives the robot safely around the obstacle but it does not make the robot steer to the side as early as the PP mode does, in presence of a person. A

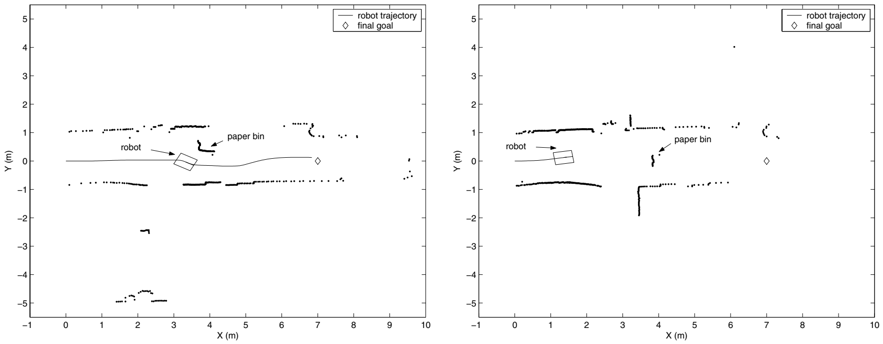

Fig. 8. Regular obstacles handling. On the left, the robot circumvents a paper bin placed on the left of the corridor. On the right, the paper bin is in the center of the corridor, the robot stops

second situation is shown on the right of Figure 8 in which the paper bin has been placed slightly to the right of the center of the hallway (wrt. to the robot). This is a potentially dangerous situation, because the object could be a non-detected person and it would be inappropriate to operate in ND mode, as ND would in most of the cases pass the obstacle on the left. The robot is not allowed to pass and it stops at a distance of 2.5 m from the object.

It may appear a strong measure to stop the robot in the center of the corridor, as in the second situation. But it is important to underline here that we are making the assumption that the corridor should normally be free from obstacles. So, if the robot detects something in the middle of the hallway it should take into account the hypothesis that this object could be a person. In this case the chosen strategy is to stop the robot, because any other attempt to steer (as moving to the side and then stopping) could be perceived, at such short distance (2.5 m), as unsafe and unpredictable by the undetected person.

5.3 Pilot User Study

To fully appreciate the value of such method and to fine-tune it to be socially acceptable there is a need for careful user studies. Some preliminary indications about the method have been achieved in a pilot user study in which 4 subjects have evaluated the acceptability of the robot motion patterns during passage with respect to 3 parameters: the robot speed, the signaling distance at which the robot starts the maneuver and the lateral distance kept from the person during passage (Pacchierotti et al., 2005). Two values of each parameters were tested by the subjects. It was clear from the users feedback that higher speeds were preferred. An explanation for this result is that the robot moves faster to the side; the higher speeds during passage were still not higher than 0.4 m/s so they were never perceived as intimidating. The lower speeds instead, were perceived as less safe or even annoying by the users. The higher value of the signaling distance was highly preferred by all the subjects. Although not necessary to avoid the user, a large signaling distance is important for the robot behavior to be clearly understood. An early maneuver allows the robot to signal its intent, so its behavior is perceived as trustworthy and safe by the user. No clear indication emerged about which value of lateral distance was preferred. The evaluation of this parameter will be addressed more extensively in further studies.

6 Summary/Outlook

As part of human robot interaction there is a need to consider the traditional modalities such as speech, gestures and haptics, but at the same time the spatial interaction should be taken into account. For operation in environments where users might not be familiar with robots this is particularly important as it will be in general assumed that the robot behaves in a manner similar to humans. There is thus a need to transfer these rules into control laws that endow the robot with a "social" spatial behavior.

In this paper the problem of passage of a person in a hallway has been studied and a control strategy has been presented, based on definitions borrowed from proxemics. The operation of the robot has been evaluated in a number of experiments in typical corridor settings which have shown how the introduction of social rules for corridor passage in the robot navigation system can give a contribution to the establishment of effective spatial interaction patterns between a robot and a person.

The hallway passage is merely one of several different behaviors that robots must be endowed with for operation in spaces populated by people. The generalization to other types of environments is an issue of current research.

Acknowledgements

The present research has been sponsored by the Swedish Foundation for Strategic Research (SSF) through its Centre for Autonomous Systems (CAS) and the EU as part of the Integrated Project "CoSy" (FP6-004150-IP). The support is gratefully acknowledged. H. Hüttenrauch and K. Severinson-Eklundh participated in discussions on the interaction strategy.

References

Aiello, J. R. (1987). Human Spatial Behaviour. In D. Stokels & I. Altman (Eds.), *Handbook of Environmental Psychology.* New York, NY: John Wiley & Sons.

Althaus, P., Ishiguro, H., Kanda, T., Miyashita, T., & Christensen, H. I. (2004, April). Navigation for human-robot interaction tasks. In *Proc. of the IEEE Int. Conf. on Robotics and Automation* (Vol. 2, p. 1894-1900).

Borenstein, J., & Koren, Y. (1991, Aug.). Histogramic in-motion mapping for mobile robot obstacle avoidance. *IEEE Trans on Robotics and Automation*, *7*(4), 535–539.

Burgoon, J., Buller, D., & Woodall, W. (1989). *Nonverbal Communication: The Unspoken Dialogue.* New York, NY: Harper & Row.

Chen, D., Yang, J., & Wactlar, H. D. (2004, October). Towards automatic analysis of social interaction patterns in a nursing home environment from video. In *6th ACM SIGMM International Workshop on Multimedia Information Retrieval* (Vol. Proc of ACM MultiMedia 2004, pp. 283–290). New York, NY.

Hall, E. (1966). *The Hidden Dimension.* New York: Doubleday.

Karlsson, J. (2004). *World robotics 2004.* Geneva, CH: United Nations Press/International Federation of Robotics.

Minguez, J., & Montano, L. (2004, Feb.). Nearness Diagram Navigation (ND): Collision avoidance in troublesome scenarios. *IEEE Trans on Robotics and Automation*, *20*(1), 45–57.

Nakauchi, Y., & Simmons, R. (2000, October). A social robot that stands in line. In *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems* (Vol. 1, p. 357-364).

Oriolo, G., De Luca, A., & Venditelli, M. (2002, November). WMR control via dynamic feedback linerization: design, implementation, and experimental validation. *IEEE Trans on Control Systems Technology*, *10*(6), 835–852.

Pacchierotti, E., Christensen, H. I., & Jensfelt, P. (2005, August). Human-robot embodied interaction in hallway settings: a pilot user study. In *Proc. of the IEEE Int. Workshop on Robot and Human Interactive Communication.* Nashville, TN.

Schulz, D., Burgard, W., Fox, D., & Cremers, A. B. (2001, December). Tracking multiple moving objects with a mobile robot. In *Proc. of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR).* Kauai, HW.

Vaughan, R., Gerkey, B., & Howard, A. (2003, Oct.). On device abstraction for portable, reusable robot code. In *Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems* (pp. 2121–2127). Las Vegas, NV.

Yoda, M., & Shiota, Y. (1997, September). The mobile robot which passes a man. In *Proc. of the IEEE Int. Workshop on Robot and Human Interactive Communication* (p. 112-117).