Developing Spatial Skills for Social Robots

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Abstract

Robots that navigate around people must be able to follow human social conventions in order to for non-roboticists to understand and predict the robot's motion. In order to improve social robot navigation, then, we must understand what conventions people use. This paper presents preliminary results from an observational study of older adults walking together, describes how these findings can be applied to a social robot, and concludes by discussing the multidisciplinary nature of this research.

Introduction

This research aims to develop socially competent robotic guides and companions for older adults. Unlike currently available hospital and nursing care robots that simply deliver medications (Engelberger 1993) or that can only lead people (Montemerlo *et al.* 2002), we are developing robots that can accompany people side-by-side, interacting with them socially. In a nursing home, for example, such a robot could help guide a person who has difficulty way-finding, guide and encourage residents as they walk for exercise, or support more social interaction among residents by accompanying them to common areas. We believe that such a robot will need to travel next to a person rather than leading in front of him, and must follow the same social conventions as another human would. Obeying such human conventions is particularly important for robots that operate among older adults who are unfamiliar with robotic technology and may resent or even fear technology that behaves unpredictably.

When two people walk together, they coordinate their movements with each other while observing many social conventions, such as what distance to keep from each other and how to indicate when to turn or stop. Furthermore, if either partner fails to use or respond to such conventions, the interaction becomes difficult and awkward. Despite the complexity of such interpersonal coordination, extremely little research has been done to determine exactly what people do and what social conventions they follow (Ducourant *et al.* 2005). In order to develop robots with the ability to move naturally with people, we must first understand how people (particularly older adults) walk together. This paper presents preliminary results from observational studies of older adults at a local retirement community, and discusses the potential applications of this work.

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Related work

Many researchers have addressed the idea of robots navigating with and around people. Some of the tasks addressed include standing in line (Nakauchi & Simmons 2000), passing in hallways (Pacchierotti, Christensen, & Jensfelt 2005), and joining conversational groups (Althaus *et al.* 2004). All of these have addressed specific social conventions but are not generalizable to other tasks, such as side-by-side travel. Prassler and colleagues have demonstrated a robot that can travel along-side a person (Prassler, Bank, & Kluge 2002), but this work does not account for human social conventions at all. In contrast, we take a more multidisciplinary approach, using ethnographic methods to study people's behaviors before designing and developing the technology.

A recent study analyzed people's perceptions of two different person-following behaviors (Gockley, Forlizzi, & Simmons 2007). In the first behavior the robot always drove toward the person's current location, while in the second behavior the robot attempted to follow the exact path that the person walked. While both behaviors had similar performance on quantitative measures (such as distance maintained and tracking performance), a pilot study found that people qualitatively preferred the "direction-following" behavior over "path-following," rating the former as more natural and as closer matching their expectations. This work, which we believe will serve as a foundation for the side-by-side travel described above, showed that people do interpret a robot's behavior according to human social conventions and, furthermore, that people expect a robot to behave in a human-like manner.

Observational study

We performed an observational study of how older adults in a local retirement community walk together, using ethnographic methodologies borrowed from social anthropology.

Procedure

Observations took place at a local retirement community. Investigators used an ethnomethodologic approach that involved making observations as unobtrusively as possible

Escorting		
Leader	*Follower*	*Count*
Resident	Resident	4
Resident	Non-resident	1
Non-resident	Resident	14
Non-resident	Non-resident	5
Social		
Pairing		*Count*
Both residents		15
Both non-residents		7
Resident with non-resident		8

Table 1: Number of walking pairs observed, separated by situation (escorting or social). Total pairs observed: 54.

while seated, standing, or walking within 20 feet of participants (investigators were somewhat conspicuous by virtue of their younger age in comparison to the community residents). Genders of the participants and observation locations were documented. Observations were made of pairs of people regarding:

1. what route they took, including stops;
2. the relative ages of the walking companions (e.g. two older adults, one older adult and one staff person, etc.);
3. how the companions positioned themselves relative to each other;
4. whether one person was leading or escorting the other (if so, who was in which role); and
5. the amount of social interaction, both of the two walkers, and of any interactions with people outside of their pair.

Residents and staff received prior notice of the study through the community's weekly newsletter, and the experimenter willingly explained the nature of the study when requested during observations. To protect residents' privacy, no personally identifying information was collected and no photographs were taken.

Results and discussion

Observations were performed in three-hour blocks on 4 days, for a total of 12 hours. Data was collected on 54 pairs of people. The situational breakdown of people can be seen in Table 1.

Escorting behaviors We observed several behaviors specific to escorting situations, including gestures, physical contact, and body movements to indicate direction.

- *Gestures and physical contact.* In escorting situations, the leader often used gestures or physical contact to indicate the intended direction. We observed five instances of the leader pointing toward a destination, and four instances of the leader using physical contact—a hand on the follower's arm, shoulder, or back—to direct the follower.
- *Body movements.* Intuitively, we suspect that leaders use movement into or out of their partner's personal space in order to indicate turns along the path. Unfortunately, these movements are subtle and difficult to detect in this sort of observational study. We observed several instances, typically involving a non-resident leading a resident, where the leader appeared to speed up on outside turns and slow down on inside turns, allowing the follower to maintain a constant speed. In addition, we observed one instance where such body movements failed to properly convey a turn; the leader began to turn a corner by moving away from the follower, but the follower did not immediately correct her movement. Rather, once the pair had separated to about 1.5m between them, the leader turned to the other, gestured, and said, "This way." That is, a failure in leading via body movements was corrected with a gesture and spoken command.

Interpersonal distances All distances (both side-to-side and front-to-back) between companions were highly variable—not just across different pairs of people, but also within individual pairs as they walked. However, we can note that pairs consisting of two residents walking socially or of a non-resident and a resident in an escorting situation tended to maintain much closer side-to-side distance (0.5m or less) than most other types of walkers.

Obstacles and bottlenecks We observed three main behaviors when pairs encountered obstacles (e.g. another person or object in the way) or bottlenecks (narrowing of the passageway):

1. *Simultaneous movement.* Both partners simultaneously move to the side. This behavior was observed only once; both partners were able-bodied and had sufficient space in the hallway to avoid the obstacle.
2. *Speed increase.* One partner speeds up to pass the other and proceeds first (observed 8 times). This behavior occurred primarily in social accompaniment situations, and in particular occurred when one partner was able-bodied but the other was not, in which case the able-bodied partner proceeded first.
3. *Speed decrease.* One partner slows down and allows the other to proceed ahead. This behavior was observed 12 times, in the following situations:
   - When both partners were able-bodied, the partner closest to the obstacle fell behind while the other partner proceeded straight ahead.
   - When a more able-bodied person was leading a less able-bodied follower, the able-bodied leader slowed down, allowing the other to pass, and often used physical contact (such as a hand on the other's shoulder) to continue guiding the other from behind.
   - This behavior was also observed in social accompaniment situations between an able-bodied and a less able-bodied person, in which case the able-bodied person slowed down to let the other pass first.

Unexpected stops We observed five instances of one partner stopping suddenly—to speak to a passerby or to search through a bag—without the other partner's prior knowledge. In each of these cases, the other partner continued on for 0.5–2.5m before stopping, then turned to face the stopped

partner. Generally, the other person did not reverse direction, but rather waited in place for the first to resume walking.

Social interaction In general, partners who were conversing with each other tended to look forward, with occasional glances toward the other partner. However, more detailed observations (such as video coding) may be necessary to fully understand the use of gaze in such situations.

Applications

The results from the observational study described above can be viewed as suggestions for mobile robot behavior in the context of traveling side-by-side with a person. Specifically, a robot must:

- Maintain appropriate distance from the person. As discussed, this distance should vary according to the particular social situation (escorting or not). Additionally, the ideal position for the robot to maintain may be somewhat different than the typical distance people keep between themselves; people may not have the same concept of personal space with regard to robots (Walters *et al.* 2005). Determining the appropriate distance will require empirical testing.
- Navigate obstacles and bottlenecks in a socially acceptable manner. In general, the robot will need to either speed up or slow down to allow it and the person to pass the obstacle single-file; the exact behavior will depend on the particular situation and whether the robot is leading or following.
- Speak or gesture appropriately to build common ground regarding the path to take.
- Recognize and understand the person's behaviors in order to respond correctly to unexpected movements, such as sudden stops or turns.

These behaviors are all necessary—though likely not sufficient—components of the skill set that a robot will need to accompany a person in a socially acceptable way. We argue that the only way to develop robots that are capable of such rich interactions with people is to proceed in this multidisciplinary manner: taking cues from psychology and anthropology, study how people interact with each other; model human behavior on a robot; and finally, in conjunction with developing the behavioral models, we must perform empirical testing of the robot's behavior with naïve, untrained users. Such studies are necessary to determine whether the robotic technology can meet the needs of the people it is intended to assist.

Conclusion

This paper has reported on a first step toward developing robots with social spatial skills. From observing how older adults walk in pairs, we can draw conclusions about how a robot should behave in order to accompany a person, side-by-side. The next steps in this research are to begin implementing these behaviors on a mobile robot and to study how people then react to the robot.

The nature of this research is highly multidisciplinary, drawing from psychology, sociology, anthropology, and design, as well as the wide variety of sub-fields within robotics. The research discussed here represents a collaboration between researchers not only from technical disciplines such as robotics and human–computer interaction, but also from nursing and from design. We firmly believe that such multidisciplinary collaboration is essential not only to socially assistive robots, but also to all aspects of human–robot interaction.

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References

Althaus, P.; Ishiguro, H.; Kanda, K.; Miyashita, T.; and Christensen, H. I. 2004. Navigation for human-robot interaction tasks. In *Proceedings of the 2004 IEEE International Conference on Robotics and Automation*, 1894–1900.

Ducourant, T.; Vieilledent, S.; Kerlirzin, Y.; and Berthoz, A. 2005. Timing and distance characteristics of interpersonal coordination during locomotion. *Neuroscience Letters* 389(1):6–11.

Engelberger, J. F. 1993. Health-care robotics goes commercial: The Helpmate experience. *Robotica* 11(6):517–523.

Gockley, R.; Forlizzi, J.; and Simmons, R. 2007. Natural person-following behavior for social robots. In *Proceedings of Human–Robot Interaction*.

Montemerlo, M.; Pineau, J.; Roy, N.; Thrun, S.; and Verma, V. 2002. Experiences with a mobile robotic guide for the elderly. In *Proceedings of the National Conference of Artificial Intelligence (AAAI 02)*, 587–592.

Nakauchi, Y., and Simmons, R. 2000. A social robot that stands in line. In *Proceedings of the Conference on Intelligent Robots and Systems (IROS)*, 357–364.

Pacchierotti, E.; Christensen, H. I.; and Jensfelt, P. 2005. Human-robot embodied interaction in hallway settings: a pilot user study. In *Proceedings of the IEEE International Workshop on Robots and Human Interactive Communication (RO-MAN)*, 164–171.

Prassler, E.; Bank, D.; and Kluge, B. 2002. Key technologies in robot assistants: Motion coordination between a human and a mobile robot. *Transactions on Control, Automation and Systems Engineering* 4(1):56–61.

Walters, M. L.; Dautenhahn, K.; te Boekhorst, R.; Koay, K. L.; Kaouri, C.; Woods, S.; Nehaniv, C.; Lee, D.; and Werry, I. 2005. The influence of subjects' personality traits on personal spatial zones in a human-robot interaction experiment. In *Proceedings of CogSci-2005 Workshop: Toward Social Mechanisms of Android Science*, 29–37.