Robot-Assisted Shopping for the Blind: Haptic and Locomotor Spaces in Supermarkets

Vladimir Kulyukin
Computer Science Assistive Technology Laboratory (CSATL)
Department of Computer Science
Utah State University
Logan, UT, 84322
vladimir.kulyukin@usu.edu

Introduction

Research on spatial cognition and navigation of the visually impaired distinguishes two spatial categories: locomotor and haptic (Ungar 2000). The haptic space is defined as the immediate space around the individual that can be sensed by touch or limb motion without any bodily translation. The locomotor space is defined as a space whose exploration requires locomotion. In the absence of vision, the frames align best in the haptic space. In the locomotor space, as the haptic space translates with the body, lack of vision causes the frames to misalign, which negatively affects action reliability. Giving the visually impaired equal access to environments that the sighted take for granted entails designing interfaces to the haptic and locomotor spaces in those environments that either eliminate the necessity of alignment or enable the visually impaired to align the frames when necessary.

What environments should be targeted first? In cataloguing the most functionally difficult environments for the visually impaired, Passini and Proulx (Passini & Proulx 2000) top their list with shopping complexes. Grocery shopping is an activity that presents a barrier to independence for many visually impaired people who either do not go grocery shopping at all or depend on sighted guides, e.g., store staffers, spouses, and friends. Can robots function as effective interfaces to the haptic and locomotor spaces in the supermarket? Yes, they can! Traditional navigation aids, such as guide dogs and white canes, can act as interfaces to the haptic space in the environment by enhancing the blind individual's perception around the body. However, neither guide dogs nor white canes can effectively interface to locomotor spaces, because they cannot help their users with macro-navigation, which requires topological knowledge of the environment. It is true that sighted guides ensure the reliable maneuvering of the haptic space, but only at the expense of independence. Loss of independence translates into loss of privacy. Our experience with visually impaired individuals in our previous robot-assisted shopping experiments convinced us that quite a few of them are not willing to use store staffers when shopping for personal hygiene items, medicine, and other products that require discretion (Kulyukin, Gharpure, & Nicholson 2005). We believe that, in order to function as an effective interface to the haptic and locomotor spaces in the supermarket, the robot must satisfy a twofold objective: in the locomotor space, the robot must eliminate the necessity of frame alignment and, in or near the haptic space, the robot must cue the shopper to the salient features of the environment sufficient for product retrieval.

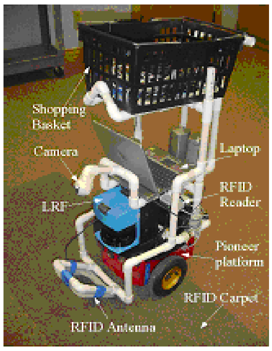

Figure 1: RoboCart.

A Trichotomous Spatial Ontology

Spatial ontologies come about when we attempt to categorize space according to the ways we interact with it (Tversky *et al.* 1999). Freundschuh and Egenhofer (Freundschuh & Egenhofer 1997) give a comprehensive review of previous work on categorization of space and distinguish six categories based on manipulability, locomotion, and size and use their ontology to describe previous ontologies of space in the geography literature. We contribute to this line of research a trichotomous ontology of space in a supermarket. This trichotomy is an extension of the dichotomous ontology (haptic vs. locomotor) currently used by many researchers on spatial cognition of the visually impaired. Our trichotomy is certainly incomplete. We developed it solely for the purposes of describing the interactions between visually impaired shoppers and RoboCart, our robotic shopping assistant shown in Figure 1.

RoboCart assists the shopper in two stages. It first guides the shopper into the vicinity of the desired product and then instructs the shopper on how to maneuver the haptic space within that vicinity. In the first stage, RoboCart interfaces the shopper to the locomotor space, guiding the shopper to the required aisle section and interacting with other shoppers by asking them to yield the way when a passage is blocked. In the second stage, RoboCart cues the shopper to some salient features of the environment near the haptic interface through voice instructions grounded in the shopper's egocentric frame of reference. The design of RoboCart reflects this dual interface functionality insomuch as the device consists of two modules: locomotor and haptic. The locomotor module consists of a Pioneer 2DX mobile robotic base from ActivMedia, Inc. upon which a wayfinding toolkit is fitted in a PVC pipe structure. A shopping basket is mounted upon the PCV structure, as shown in Figure 1. The PVC structure forms a firm handle at the lower abdomen level. A 10-key numeric keypad is attached to the handle for giving instructions to RoboCart. The rigid PVC handle of RoboCart gives the user useful haptic feedback about the maneuvers that RoboCart performs. Using the numeric keypad, the shopper can either browse through a list of products or enter a product number. Once the shopper confirms the selection, RoboCart guides the shopper to the vicinity of the product. The haptic module consists of a wireless omni-directional barcode reader. The reader is ergonomically modified with a plastic structure that helps the blind shopper align the barcode reader with the shelf. After RoboCart brings the shopper in the vicinity of the product, RoboCart uses the shopper's egocentric frame of reference to instruct the shopper through synthetic speech on how to find the product, e.g. *Honey Nut Cheerios is on the top shelf to your right*. The shopper finds the shelf and uses the barcode to scan the barcodes on that shelf. The product name of each scanned barcode is read to the shopper.

To describe how the visually impaired shopper interacts with the supermarket space using RoboCart, we introduce the category of target space. The target space is the shopper-centric subspace of the locomotor space in which the shopper perceives the target product to be. The target space is always defined with respect to a specific target product. Haptic cues in the target space act as external reference points during the shopper's maneuvering of the haptic space in the target space until the haptic space contains the product.

Experiments

We formulated several research hypotheses to test how well RoboCart functions as haptic and locomotor interface to the supermarket.

- **Hypothesis 1:** *If the robot is consistent overtime in how it sets up the target space with respect to a given product and verbally orients the shopper in the target space, the shopper's efficiency of maneuvering the haptic space in the target space increases with experience in the target space where experience is measured as the number of shopping iterations.*
- **Hypothesis 2:** *The shopper's efficiency of maneuvering the haptic space in the target space is inversely related to the area of the target space.*
- **Hypothesis 3:** *The shopper's efficiency of maneuvering the haptic space in the target space is inversely related to the complexity of the target space.*
- **Hypothesis 4:** *In the absence of any prior knowledge of the target space, minor differences in sensory abilities affect the target space performance.*
- **Hypothesis 5:** *The location of the product on the shelf (top, middle, bottom levels) affects the performance.*

Ten visually impaired participants from various locations in Utah were recruited for the experiments through the Utah Chapter of the National Federation of the Blind (NFB) in Salt Lake City, Utah. The Utah NFB Chapter provided us with a list of visually impaired Utah residents. Each individual on the list was first contacted by e-mail. The e-mail briefly described RoboCart and the experiments and asked the addressee if he or she would be interested in participating in the experiments. A brief phone interview was conducted with all those who responded positively. The inclusion criteria were: 1) the participant must be ambulatory; 2) the participant may not have any hearing or cognitive impairments; 3) the participant must understand English; and 4) the participant must be willing to travel to Logan, Utah, for a period of two days. Ten participants were thus selected. Each of the selected participants was transported to Logan, Utah, by vehicle for a period of two days and was paid a $90 honorarium.

The procedure consisted of two stages. First, the individual was given a 30 minute introduction to RoboCart in our laboratory. The participant was trained in using RoboCart's keypad and used RoboCart to navigate a short route in the office space around the laboratory. The participant was then asked to take a technology readiness survey (Parasuraman 2000) which was used to calculate the participant's Technology Readiness Index (TRI). Second, the participant was driven to Lee's MarketPlace, a supermarket in Logan, Utah, and asked to use RoboCart to shop for several products. Twelve products were chosen from two aisles: 4 products from bottom shelves, 4 products from middle shelves, and 4 from top shelves. In Lee's MarketPlace, each aisle consists of several shelf sections. A shelf section spans 4 to 5 meters in length and consists of 5 to 8 shelves. The selected products were divided into 4 sets. Set 1 included 3 products on top shelves; Set 2 included 3 products on middle shelves; Set 3 included 3 products on bottom shelves; Set 4 included one product on a top shelf, one product on a middle shelf, and one product on a bottom shelf. Five shopping iterations were conducted for each product set. The following measurements were taken during each run: 1) navigation time from location to location; 2) product retrieval time (time interval that starts when RoboCart stops and instructs the shopper on where the product is in the target space and ends when the shopper puts the product into RoboCart's basket); 3) the distance between the robot and the product; and 4) the number of other shoppers encountered on route. We also recorded observations regarding specific haptic cues used by the participants to find products. Two observers accompanied the participants on every run: the first observer was monitoring RoboCart; the second observer was making and recording measurements and observations.

Results

Given the space limitations, we give the results without graphs and tables. In testing hypothesis 1, we found that the participant's efficiency in maneuvering the haptic space in the target space appears to improve with experience. It is reasonable to expect that the shopper's performance in the target space eventually reaches an asymptote and becomes optimal given the participant's sensory, cognitive, and physical abilities. In testing hypothesis 2, we found a very low correlation coefficient (Pearson's product moment) of 0.37 between the target space area and the shopper's performance, which suggests that Hypothesis 2 may not hold for our sample. To test Hypothesis 3, we used the product density as the measure of the target space complexity. The product density was computed as the number of products per foot between the robot and the target product on the correct shelf. The measurement was motivated by our previous ergonomic studies where it was found that the shoppers easily find the correct shelf from the robot's instructions but may have difficulties scanning the barcodes on the shelf. We found a general trend of decrease in efficiency with increasing complexity. Product retrieval time and target space complexity have a correlation coefficient of 0.7. To test Hypothesis 4, we compared how the participants performed with respect to each other. During the first shopping iteration, the shopper does not have any knowledge about the target space. Since the target space complexity is the same for all shoppers for any given product, it is sensible to suggest that the shopper's individual sensory and physical abilities will make the greatest difference in the absence of any knowledge of the target space. Using the data from all participants after the first shopping iteration, one-way ANOVA was used to test for a statistically significant difference in the target space performance between he participants. No significant difference in performance was found (df = 8, F = 1.504, P = 0.17). One explanation is that RoboCart minimizes minor sensory differences of the shoppers and enables them to retrieve products in the absence of any knowledge of the target space. Minor differences in sensory abilities appear to make a difference given some knowledge of the target space. The shopper may be able utilize his or her sensory abilities optimally after receiving some exposure to the target space, but not before. Hypothesis 5 is based upon our conjecture that some parts of the target space are more easily accessible than others. We expected that there might be significant differences in performance of the shoppers between retrieving products from top, middle and bottom shelves. Using the data collected after the first iteration, one-way ANOVA was computed for three samples of runs, each of size 40. It was found that there was significant difference in performance (df = 2, F = 4.737, P = 0.011). We were now interested in finding out if knowledge of the target space was a factor. One-way ANOVA was computed on three samples of runs, each of size 40, obtained after the fifth iteration. No significant difference in performance was found (df = 2, F = 0.2701, P = 0.76). Some knowledge of the target space appears to make different parts of the space equally accessible. We also tested whether the technology readiness index (TRI) (Parasuraman 2000) is an indicator of how well the shopper performs with RoboCart. Each participant was given the TRI survey. The survey consists of four groups of questions to be answered on a Likert scale: Optimism, Innovativeness, Discomfort, and Insecurity. All four TRI components have low correlation coefficients with performance: 0.47, 0.29, 0.53 and 0.22, respectively. While the TRI may be a reliable predictor of a user's readiness to use desktop computer technologies, it was not a reliable predictor of how the participants in our sample performed with RoboCart.

Conclusions

An assistive shopping device for the visually impaired that ensures independence must provide the shopper with interfaces to the haptic and locomotor spaces in the supermarket. These interfaces should either eliminate the necessity of frame alignment or enable the visually impaired to reliably align the frames. Robots can function as interfaces to the haptic and locomotor spaces in supermarkets by eliminating the need of frame alignment in the locomotor space and cuing the shopper to the salient features of the target space sufficient for product retrieval.

The paper can be extended with a detailed analysis of the experiments and the graphs.

References

Freundschuh, S., and Egenhofer. 1997. Human conceptions of spaces: implications for geographic information systems. *Transactions in GIS* 2(4):361–365.

Kulyukin, V.; Gharpure, C.; and Nicholson, J. 2005. Robocart: Toward robot-assisted navigation of grocery stores by the visually impaired. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE/RSJ.

Parasuraman, A. 2000. Technology readiness index (tri): A multiple-item scale to measure readiness to embrace new technologies. *Journal of Service Research* 2(4):307–320.

Passini, R., and Proulx, G. 2000. Wayfinding without vision: an experiment with congentially totally blind people. *Environment and Behavior* 22:333–359.

Tversky, B.; Morrison, J.; Franklin, N.; and Bryant, D. 1999. Three spaces of spatial cognition. professional geographer. *Environment and Behavior* 51(4):516–524.

Ungar, S. 2000. Cognitive mapping without visual experience. In *Kitchin, R. and Freundschuh, S. (Eds.) Cognitive Mapping: Past, Present, and Future*. London: Routledge and Kegan.