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Human Differences in Navigational Approaches during Tele-Robotic Search

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This study investigated the navigational approaches used by humans when operating a simple tele-robot in a simulated search and rescue operation. Tele-robots are being increasingly used in safety-critical operations. During tele-operation, the situational awareness of tele-robot operators needs to be supported. Navigation depends on psychological skills of perception and cognition, and can utilize different problem solving strategies. However, there is limited knowledge of how operators develop situational awareness while navigating tele-robots. The study was conducted to understand if there were distinctive, identifiable strategies in the way operators navigated. When participants manually tele-operated a robot in a remote physical environment, two distinct navigation strategies were found (labeled driver method and searcher method). The result of this work can be used to inform the design of human-centric tele-robot navigational algorithms that can support a variety of human navigation strategies.

INTRODUCTION

Tele operated robots (tele-robots) are increasingly used as integral members of teams conducting safety-critical missions, such as urban search and rescue operations (Yanco and Drury 2004). For instance, search and rescue tele-robots are sent into the disaster area to act as the remote eyes of the team and are operated manually by an operator stationed outside of the disaster area (Casper & Murphy 2002; Ruangpayoongsak et al. 2005).

A critical function is navigation of the robot. Human beings rely on a wealth of information to navigate in the real world: psychological skills of perception and cognition, motor skills in location, physical environmental cues, and technological assistance (i.e. information and transportation systems) (Montello & Sas, 2006). However, the remote tele-operation of a robotic vehicle involves at best a fraction of the available information: an incomplete knowledge of the environment, limited sensor information, and inadequate feedback (Gonzales-Banos & Latombe, 2002). Thus one of the pressing concerns of robot designers is the ability to support the operator development of situation awareness. However, there is limited knowledge of how operators navigate tele-robots in order to gather the information needed to develop situational awareness.

The robots used in search and rescue typically have limited on-board sensors, leading to limited information feedback for the operator. Some are equipped with a video camera that provides a narrow view of the environment, significantly more restrictive than the human eye (Casper & Murphy 2002). Poor camera placement and video quality can also contribute to impaired operator performance (Hughes & Lewis 2004). Due to the difficulty in providing a rich enough data set to operators, much of the focus of recent work has been to

design the human out of the operation altogether by designing robots that can navigate autonomously (Chien et al. 2010; Worrall, 2008; Hughes & Lewis, 2004; Ruangpayoongsak et al., 2005; Goodrich et al. 2001; Lewis et al. 2003; Wang et al. 2009; Casper & Murphy, 2002; Kitano et al. 1999). However, both human perception and problem solving abilities are vital in successful search and rescue. What is needed are ways to support natural human navigation strategies in as efficient a manner as possible. The first step is to develop a better understanding of how humans naturally navigate a tele-operated robot.

Despite the advances in autonomous navigation, the technological capabilities of autonomous perception lag far behind that of human capabilities (Murphy and Burke 2005). While humans are well equipped to use their natural senses for perception, the incomplete information available to the tele-robot operator severely reduces the operator's situational awareness. This awareness is needed for the operator to establish his/her surroundings, understand current information, and apply this information in planning for future events (Endsley, 1988). In one study, robot operators spent 54% of their time attempting to establish information about the state of the robot, the environment, and the robot's location within the environment (Burke 2004), while in another, operators spent 29.8% of their time trying to determine where the robot was (Yanco & Drury, 2002). Previous work has established that 76% of situation awareness errors are due to perceptual problems (Jones & Endsley, 1996). The focus of improving tele-robotic systems should include efforts to support human perception and more generally the development of situational awareness. In search and rescue, navigation strategies can impact the information gathered, and the resulting situation awareness. Several studies have tested rescue robotics in real-world scenarios with a focus on measuring the performance and situational awareness of the operators (Burke, 2004;

Casper & Murphy, 2002). These prior studies demonstrated that increased situational awareness in searching tasks is linked to increased performance.

Tele-Navigation as Perception

When humans manually operate a tele-robot during a search task, they are able to use the navigation of the robot as a way to gather information needed to support the development of situational awareness. Research focused on the way in which people orient themselves in physical space and navigate from place to place, known as wayfinding, suggests that there are distinctive differences in the way humans, particularly between males and females, navigate around an unfamiliar landscape (Chin-Teng et. al. 2012). Wayfinding is often decomposed into a four step process: 1) orientation, 3) route decisions, 3) route monitoring, and 4) destination recognition (Downs & Stea, 1973). Wayfinding research has typically focused on the movement of pedestrians and little work has focused on the navigation methods of tele-robot operators (Meilinger et. al. 2008). However, due to the involvement of humans in search tasks, a key problem is determining how humans search an environment, and how the search approach influences the operator's ability to complete the task (Chien et al. 2010).

Navigation as Knowledge

Alternatively, navigation strategies may be governed by the type of knowledge the operator has of the domain. Additionally, individual preferences can govern how information is collected to support a particular navigation strategy. Traditionally, descriptions of navigational knowledge stages are used to explain how people learn to navigate in a geographical domain. Throndyke (1980) postulated three types of navigational strategies:

1. *Landmark Knowledge*: orientation exclusively via highly salient visual landmarks.
2. *Route Knowledge*: understanding is characterized by the ability to navigate from one location to another.
3. *Survey Knowledge*: knowledge resides in an internalized map.

The study described in the next section was conducted to understand if there were distinctive, identifiable strategies in the way operators navigated.

METHODS

Hypothesis

To observe the manner in which tele-robot operators complete search tasks, a search and rescue scenario was developed for this study. A highly simplified setup and a simple robot were used to better isolate the natural tele-navigational behavior from factors such as the presence of technological aids or highly difficult navigational challenges. In the search and rescue, navigation decisions primarily impacted the wayfinding processes of orientation and route decision. In this study, the approaches and performance of operators were

observed as they manually navigated a tele-robot through a simulated disaster scenario to find victims. It was hypothesized that, as in pedestrian wayfinding, there would be distinctive, identifiable approaches in the way operators navigated the tele-robot, primarily characterized by their strategies to orient themselves to the environment and their moment-to-moment route decisions.

Equipment

A simulated disaster area was constructed using 1.2m tall particle board. Standards from the National Institute of Standards and Technology (NIST) were used to guide the design of the constructed area. These standards describe the state of buildings in various stages of collapse and as a result varying levels of search difficulty: yellow is the simplest level, orange is a more difficult level, and red is the most difficult level (Jacoff et al. 2003). The area was designed with elements from the yellow and orange levels, with objects on the floor, narrow passageways, and wall materials such as Plexiglas. An image of the constructed area is shown in Figure 1.

Figure 1. The environment set up for exploration by the tele-robot. Walls were 1.2m tall. Targets for rescue were baby dolls place in this simulated childcare environment. Distractors were also placed throughout.

To explore the area, participants used a programmable radio-controlled robot--the Spy Video TRAKR. While the TRAKR came equipped with its own camera, the video quality was insufficient to identify the targets in the search area. Consequently, a wireless camera with a resolution of 640x480 pixels and a frame rate of 10 frames per second was attached to the top of the robot. An image of the robot is shown in Figure 2. The video stream was recorded for later analysis using Debut Video Capture software.

Figure 2. Robot used in study.

For this study, five targets were placed within the search area. The targets were baby dolls which were used to simulated babies who were trapped in a daycare center. The five targets used are shown in Figure 3.

Figure 3. Images and location of simulated victims.

Similarly, the debris strewn around the area consisted of baby-related materials (ex. toys, small clothes, bottles). This debris served as distractor items during the target search. Examples of the debris used as distractor items are shown in Figure 4.

Figure 4. distractor items in search area.

Participants

Twenty-three participants (13 female, 10 male) completed this study. The participants were primarily recruited from the population of a large Midwestern university. None of the participants had prior experience with tele-robotics or search and rescue operations.

Procedure

After obtaining consent, the participant was informed that this experiment would involve remotely navigating a robot. The robot would be maneuvered using a joystick and the path in front of the robot would be observed via a video stream viewed on a computer. Participants were then shown the robot and given instructions on its operation. Next, participants were allowed to practice navigating, first while observing the robot directly and then indirectly by viewing the video stream of the practice area. Once the participant indicated that he or she felt comfortable operating the robot (usually 5-7 minutes of practice), the robot was taken to the search area and placed at the entrance. The participant was then instructed that there were an unknown number of children, simulated by baby dolls, deserted in a daycare and their task was to locate all of the victims by navigating the robot through the search area. The participant was also informed that due to the time-

sensitive nature of the task, there would be only ten minutes to navigate around the area. The participant then started the navigation and search task. When the participant felt a target had been identified, he or she indicated the identification verbally and an experimenter recorded the identification and whether it was an actual target or a distractor item. When the ten minutes expired, the participant was stopped from navigating. During the task, the video stream observed by the participant was recorded for later analysis.

Measures

After the navigation and search task was completed, the participants were asked to complete three surveys. The first survey was a situational awareness survey (SART: Taylor, R. M., 1990). The second survey was a mental workload survey (NASA-TLX: Hart & Staveland, 1988). The third survey consisted of demographic questions.

In addition, video of the path of the tele-robot was analyzed to determine distance travelled, amount of turning, stationary periods, and linear motion.

Data Analysis

Three types of data were analyzed during this study: video of the path of the tele-robot, SART scores, and NASA-TLX scores. The primary data for this study was the video data. To analyze the videos, each path of the tele-robot as shown on the videos was transferred to a map of area. The distance travelled by each participant was calculated by tracing the path drawn on these maps with a Scale Master Classic digital plan measure and scaled by the appropriate factor (1:4). In addition to recording the path of the tele-robot, the videos were reviewed for patterns in the movement of the tele-robot around the area. Since our hypothesis postulated potential differences in strategies to orient and moment-to-moment route decisions, particular attention was paid to the amount of turning, stationary periods, and linear motion.

Limitations

While this study was conducted in a real-world environment, there were some limitations which prevented the study from fully representing a real-world environment. One of these limitations was using small baby dolls instead of life-sized dolls as victims. While this measure significantly increased the practicality of the study, it also required the participants to make additional judgments when distinguishing between victims and distractions such as the appropriate size and appearance of victims. In addition, the difficulty of maneuvering around the area was considerably easier when compared to maneuvering around an area that was affected by a disaster such as a building collapse or a power outage. However, given the significant difficulties experienced by the participants in navigating around the area, this limitation was advantageous as adding more navigational challenges would likely have obscured the navigational approaches observed.

RESULTS

Navigational Approach Selection

Two approaches were identified from the patterns observed in the video data. The first approach, which was adopted by twelve of the participants, was termed the *driver method*. For this approach, participants spent most of the time in linear motion with stop or turning primarily occurring only when an obstacle was encountered. The second approach, which was adopted by eleven of the participants, was termed the *searcher method*. For this approach, participants spent a significant portion of the time stationary or in rotation with linear motion primarily occurring only when the surrounding area was observed repeatedly.

Further support for this distinction was found after comparing the distances travelled by the participants to the type of approach adopted. Distance travelled was found to be highly correlated with navigational approach ($R = 0.826$, $P = 0.0001$) with those who adopted the driver method traveling farther distances. It should be noted that the increased distance travelled did not necessarily lead to increased area coverage due to considerable path overlap.

Performance, Situational Awareness, and Mental Workload

The remaining data was analyzed to identify if the navigational approach was correlated with performance, situational awareness, or mental workload. Neither approach was correlated with performance, situational awareness or mental workload. As expected, participant performance was correlated with situational awareness ($R = 0.537$, $P = 0.008$).

Subject Differences

The navigational approach selection, but not performance, was correlated with gender ($R = 0.489$, $P = 0.018$), with males preferring the driver method and females preferring the searcher method.

DISCUSSION

The hypothesis stated that the operators would not be uniform in their selection of a navigational approach when operating a search-and-rescue tele-robot. Furthermore, it was believed that the approaches would be sufficiently distinct that they could be categorized.

The results of the study supported the hypotheses as two approaches were identified. One approach observed in this study was termed the *driver method* in which participants spent most of the time in linear motion with stop or turning primarily occurring only when an obstacle was encountered. This method was found to be the preferred approach for males. The second approach was termed the *searcher method* in which participants spent a significant portion of the time stationary or in rotation with linear motion primarily occurring only when the surrounding area was observed repeatedly. This method was found to be the preferred approach for females. These results align with those identified by Chin-Teng et. al. (2012) in his study on gender differences in wayfinding.

Research has consistently shown a difference in spatial ability (e.g. mental rotation) between men and women (in favor of men) (e.g. Halpern, 2000; Linn & Peterson, 1985, as references in Lawton & Kallai, 2002). Some researchers have suggested that gender differences in spatial ability are the result of different strategies in finding a destination. In one set of studies, women reported that they were more likely to rely on landmark knowledge, which is characterized by an orientation that relies on the physical features visible from one location to the next. Men reported that they are more likely to rely on map-based orientation (Lawton, 1994, 1996, 2002). To what extent the two navigational approaches observed in this study are due to gender-based differences in information gathering strategies is an area that merits further study.

While the aforementioned correlations were identified, neither approach was shown to be more advantageous in terms of identifying more targets or identifying fewer distractors. Participant performance, while not correlated to maneuvering approach, was highly correlated with situational awareness. Also, the driver method was shown to be more efficient in terms of distance travelled versus time and, given a different task, this feature may prove advantageous.

CONCLUSION

This study represents one of the first attempts to describe how humans prefer to navigate tele-robots in a real-world environment. These preferences can serve as insight for future design principles which can improve the effectiveness of tele-robot usage in search-and-rescue operations. In particular, the results may prove useful in the design of navigational algorithms that support multiple search strategies that align with human expectations and preferences. Navigational algorithms have the potential to address many of the challenges that are encountered when operators manually operate a tele-robot. Potential improvements include reduced mental workload, improved hazard avoidance, and decreased search time. However, before these algorithms can be deployed a number of difficulties must be addressed. One of the primary difficulties is how to design human-centric algorithms. A human-centric algorithm is one which provides full coverage and allows the operator to maintain situational and spatial awareness. The closer the navigation strategy aligns with the particular operator's natural strategy, the easier it will be for the operator to understand the information collected. Two ways to increase operator awareness is to support the operator's ability to predict the future path of the robot and to minimize the discrepancy between the path the operator desires and the path selected by the algorithm. To support the design of human-centric algorithms, future work extend the results of this study to determine if, as with manual navigation approaches, there are certain navigational algorithms that are more in-line with the natural navigational tendencies of humans. By designing systems which support human abilities the overall performance of the operation will be significantly enhanced.

REFERENCES

- Burke, J. L., Murphy, R. R., Coovert, M. D., & Riddle, D. L. (2004). Moonlight in Miami: Field study of human-robot interaction in the context of an urban search and rescue disaster response training exercise. *Human-Computer Interaction*, 19(1-2), 85-116
- Casper, J., & Murphy, R. (2002). Workflow study on human-robot interaction in USAR. In *Proceedings of the IEEE International Conference on Robotics and Automation*, 2, 1997-2003.
- Chien, S. Y., Wang, H., & Lewis, M. (2010). Human vs. algorithmic path planning for search and rescue by robot teams. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 54(4), 379-383.
- Chin-Teng Lin, Teng-Yi Huang, Wen-Jing Lin, Shu-Yen Chang, Yin-Hung Lin, Li-Wei Ko, Daisy L. Hung, Erik C. Chang, Gender differences in wayfinding in virtual environments with global or local landmarks, *Journal of Environmental Psychology*, Volume 32, Issue 2, June 2012, Pages 89-96.
- Crandall, J. W., & Goodrich, M. A. (2002). Characterizing efficiency of human robot interaction: A case study of shared-control tele-operation. *Intelligent Robots and Systems*, 2002. *IEEE/RSJ International Conference on*, 2, 1290-1295 vol. 2.
- Downs, R.J., & Stea, D. (1973). Cognitive Maps and Spatial Behavior", *Image and Environment*, 8-26.
- Endsley, M. R. (1988). Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 97-101). Santa Monica, CA: Human Factors Society.
- Endsley, M.R. (1988a). Situational awareness global assessment technique, (SAGAT) In: *Proceedings of the National Aerospace and Electronics Conference (NAECON)* (pp. 789-795). New York: IEEE. 29
- Gonzalez-Banos, H.H., & Latombe, J.C. (2002). Navigation Strategies for Exploring Indoor Environments, *International Journal of Robotics Research*, 21(10-11), 829-848.
- Goodrich, M., Olsen, D., Crandall, J., & Palmer, T. (2001). Experiments in Adjustable Autonomy. *IEEE International Conference on Systems, Man, and Cybernetics*, 3, 1624-1629.
- Halpern, D. F. (2000). *Sex differences in cognitive abilities* (3rd ed.). Hillsdale, NJ: Erlbaum.
- Hart, S. G., & Staveland, L. E. (1988). Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload*, 139-183.
- Hughes, S., & Lewis, M. (2004). Robotic camera control for remote exploration. *Proceedings of the SIGCHI conference on Human factors in computing systems*, 511-517.
- Jacoff, A., Weiss, B., Messina, E. (2003). Evolution of a Performance Metric for Urban Search and Rescue Robots. In *Proceedings of the 2003 Performance Metrics for Intelligent Systems Workshop*. 2003.
- Kitano, H., Tadokoro, S., Noda, I., Matsubara, H., Takahashi, T., Shinjou, A., & Shimada, S. (1999). Robocup rescue: Search and rescue in large-scale disasters as a domain for autonomous agents research. *Systems, Man, and Cybernetics*, 1999. *IEEE SMC'99 Conference Proceedings*. 1999 *IEEE International Conference on*, 6, 739-743 vol. 6.
- Kleiner, A., Brenner, M., Bräuer, T., & Dornhege, C. (2006). Successful Search and Rescue in Simulated Disaster Areas. *RoboCup 2005: Robot*
- Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, 30, 765-779.
- Lawton, C. A. (1996). Strategies for indoor wayfinding: The role of orientation. *Journal of Environmental Psychology*, 16, 137-145.
- Lawton, C. A. & Kallai, J. (2002). Gender Differences in Wayfinding Strategies and Anxiety About Wayfinding: A Cross-Cultural Comparison. *Sex Roles*, 47, 389-401.
- Lewis, M., Sycara, K., & Nourbakhsh, I. (2003). Developing a testbed for studying human-robot interaction in urban search and rescue. *Proceedings of the 10th International Conference on Human Computer Interaction (HCI'03)*, 22-27.
- Meilinger, T., Knauff, M. and Bühlhoff, H. H. (2008), Working Memory in Wayfinding—A Dual Task Experiment in a Virtual City. *Cognitive Science*, 32: 755-770.
- Montello, D. R. and Sas, C. (2006). Human factors of wayfinding in navigation. In W. Karwowski(Ed.) *International encyclopedia of ergonomics and human factors*, 2nd ed. pp. 2003-2008. London: CRC Press: Taylor and Francis, Ltd.
- Murphy, R. R., & Casper, J. (2002). Human-robot interactions during the robot-assisted urban search and rescue response at the World Trade Center. *IEEE Transactions on Systems, Man, and Cybernetics*, 33(3), 367-385. doi:10.1109/TSMCB.2003.811794
- Ruangpayoongsak, N., Roth, H., & Chudoba, J. (2005). Mobile robots for search and rescue. *Safety, Security and Rescue Robotics, Workshop*, 2005 *IEEE International*, 212-217.
- Taylor, R. M. (1990). Evaluation of the Situational Awareness Rating Technique (SART) as a tool for aircrew systems design. *AGARD, Situational Awareness in Aerospace Operations* 8 p (SEE N90-28972 23-53).
- P. W. Thorndyke, "Performance models for spatial and locational cognition," Rand, Washington, DC. ", *Tech. Rep. R-2676-ONR*, 1980.
- Wang, H., Chien, S. Y., Lewis, M., Velagapudi, P., Scerri, P., & Sycara, K. (2009). Human teams for large scale multirobot control (pp. 1269-1274). Presented at the 2009 *IEEE International Conference on Systems, Man and Cybernetics - SMC*, IEEE. doi:10.1109/ICSMC.2009.5345912
- Worrall, K. (2008). Guidance and search algorithms for mobile robots: application and analysis within the context of urban search and rescue. PhD thesis, University of Glasgow.
- Yanco, H. A., & Drury, J. (2004). "Where am I?" Acquiring situation awareness using a remote robot platform (Vol. 3, pp. 2835-2840). Presented at the 2004 *IEEE International Conference on Systems, Man and Cybernetics* (IEEE Cat. No.04CH37583), IEEE. doi:10.1109/ICSMC.2004.1400762