Cogn Process (2009) 10 (Suppl 2):S338–S341
DOI 10.1007/s10339-009-0299-2

EXTENDED ABSTRACT

Spatial processes in mobile robot teleoperation

Alberto Valero Gomez · Chiara Saracini · Fabiano Botta · Gabriele Randelli

© Marta Olivetti Belardinelli and Springer-Verlag 2009

Introduction

When a human operator drives a robot through a graphical user interface, he or she must have a proper situational awareness (SA), which has been considered in literature one of the measures for evaluating an interface's usefulness (Drury et al. 2007; Nielsen and Goodrich 2006; Olsen and Goodrich 2003; Scholtz et al. 2004). The commonly accepted SA definition was given by Endsley (1988) and adapted to HRI by Yanco et al. (2003). It distinguishes three components: human–robot SA, robot–human SA, and the human's overall mission awareness. Within the human–robot awareness, two aspects are important for the purposes of this paper: location awareness, defined as a map-based concept, which allows the user to locate the robot in the scenario, and surroundings awareness, which pertains to obstacle avoidance and allows the user to recognize the immediate surroundings of the robot (Drury et al. 2007). These concepts can be connected to cognitive distinction between *route knowledge* and *survey knowledge*. The route perspective is closely linked to perceptual experience: it occurs under the egocentric perspective in a "retinomorphous reference system", that makes a person able to perceive oneself in the space (Herrmann 1996), with a special emphasis on spatial relations between objects composing the scene an agent is situated in. This seems quite necessary for a correct surrounding awareness. In contrast, survey perspective is characterized by an external and allocentric perspective, such as an aerial or map-like view, allowing a direct access to the global spatial layout (Cohen 1989) and giving information about structures and global relations, but no clues about distances between objects and information about turning points, perspective and visual appearance of landmarks, for example, and this can be connected with the location awareness.

Intra-scenario operator mobility is claimed to be a strong advantage for acquiring SA within a robot teleoperation, only narrowed by portable devices' limits. In contrast, remote controlling is supposed to give interface's advantages (because it allows bigger screens and different sources of information), but very bad SA.

Our case study evaluates the performances of human operators remotely or directly driving a robot by means of diverse human–robot interfaces. When the operator is not physically in the navigation scenario, the interface must enhance his or her spatial cognitive abilities by offering multilevel information about the environment (route and survey), and this can be done mainly with complex interfaces. In contrast, if the operator is inside the scenario, part of the information can be acquired by direct observation, depending on the visibility the operator has, but the interface has to face the portable devices' limits.

In our experiment, both laser and the map views, representing respectively "route" and "survey" knowledge (Siegel and White 1975; Tversky 1991), are available in desktop and PDA interfaces. The only (but crucial) difference is that in the PDA the operator must change the

A. V. Gomez · G. Randelli
Department of Computer and System Sciences,
Sapienza Università di Roma, Rome, Italy

C. Saracini · F. Botta (✉)
Department of Psychology,
Sapienza Università di Roma, Rome, Italy
e-mail: fabianobottaster@gmail.com

displayed screen by means of tabs to switch between laser and map view, and this requires a certain time. In contrast, in the desktop interface the survey and route knowledge are always and contemporary available on the screen. Consequently, we hypothesized a better performance in spaces requiring dynamic environment orienting abilities (i.e. maze) when the operator drives the robot with the desktop than with the PDA. Contrarily, no meaningful performance differences were expected in the navigation task in which no survey information is required (i.e. narrow spaces) and information obtained from the route perspective would be enough to accomplish the task. Besides, we expected a general better performance for PDA users in the full visibility condition, as the operator has the possibility to see the robot either represented on the PDA display, either in the real environment. This could plausibly decrease the information accessibility disparities between the two interfaces and take advantage of a more salient route information access deriving from a direct environment experience. In any case, our aim was to verify whether communications latency and lower computational power associated with the PDA device would significantly influence the performance.

Method

Three experiments were run. The subjects were divided into two groups, one using the PDA interface, the other the desktop version. Each subject had a single trial and, before starting, a 20-min training, to get familiar with the interfaces.

First experiment

We used player/stage (Gerkey et al. 2003) robotics simulator. Subjects were asked to explore a virtual unknown environment of 20 × 20 m using a mobile robot equipped with laser range scanner for twenty minutes without colliding. Each candidate was randomly assigned a type of interface, so that twelve subjects had a single trial driving the robot with the PDA and the other twelve with the desktop interface. In order to "motivate" this task they were asked to look for "radioactive sources" distributed in the area, detected by a simulated sensor installed on the robot. For the exploration task analysis we have subdivided an exploration time of 10 minutes in twenty discrete values (from 0.5 to 10); then a 2 × 20 ANOVA on the explored area (m^2) was carried on with the "between-participants" factor of *interface* (desktop and PDA) and the "within-participants" factor of time (in minutes from 0.5 to 10).

Second experiment

Subjects were asked to navigate with a real Pioneer P2AT robot equipped with a SICK Laser Range Finder alongside a 15 m long path.

The environment consisted of an outdoor area in a courtyard, linked through a ramp to a corridor inside our department, composed by three different zones, all realized using reclining panels and cartons:

- *Maze*, with one entrance and one exit;
- *Narrow spaces*, very tight areas where the robot can only pass through them, without any chosen direction;
- *Clustered areas*, contain several obstacles placed irregularly and isolated in the area, such that the robot can navigate through the area choosing more than one direction.

Users did not need to find a way but just follow it from the beginning to the end. Subjects did not know the scenario and could not see it at any moment.

A one-way ANOVA on navigation times (measured in seconds) was calculated to compare the interfaces in order to see whether the differences under the PDA condition and the desktop condition had significant differences when the operator had to navigate without dealing with exploration (way finding).

Third experiment

Subjects were asked to navigate in the same real scenario as Experiment 2 with the same P2AT robot.

In this last experiment, subjects using the PDA could move in the scenario, but not enter the *arena*. The outdoor area was visible to the operator while the robot was not always completely visible. The indoor area was only partially visible through some windows located at the top of the indoor scenario and the robot was completely hidden at least half of the path. The measured variable was the time (s) required to complete the path.

Two separated ANOVAs (since the visibility variable did not vary in the desktop interface) on navigation times for each condition of PDA visibility: total visibility (TV) and partial visibility (PV) were carried out to study the PDA visibility effect on performance. For each of these analysis, the design was a 2 × 3 with the interface (desktop and PDA) as a "between-participants" factor and space type (maze, narrow spaces and clustered area) as a "within-participants" factor. Then, three planned comparisons between desktop and PDA for each space type were calculated to analyze the interface differences depending on the structural characteristics of the navigated space. Because the two analyzed population can be characterized by a normal distribution, the Student's *t* test was used to verify a statistical significant difference between them.

Results

First experiment

The covered area was considered as a measure of the performance of the exploration. The analysis showed a significant interaction between interface and time [$F(19, 361) = 13.65$, $P < 0.00001$]. A planned comparison for each level of time was calculated, indicating that at minute 1.5 of exploration the difference between desktop and PDA, in terms of explored area, is just significant ($P < 0.05$). Then it remains significant and grows at each level of time.

Second experiment

The ANOVA was not significant ($F < 1$) revealing no difference between interfaces among the driving times.

Third experiment

The first 2 × 3 ANOVA with the "between-factor" interface (desktop and PDA-TV) and the "within-factor" of *Space type* (maze, narrow spaces and clustered area) revealed a non significant interaction between them [$F(2,32) = 1.43$, $P > 0.05$]; the main effects of interface was instead significant [$F(1,16) = 6.67$, $P < 0.05$], revealing faster navigation times with the PDA interface in the TV condition in comparison with the desktop interface, independently from the space type. The second analysis (PV) showed a significant interaction between the interface (desktop and PDA-PV) and the space type [$F(2,32) = 4.41$, $P < 0.05$] (see Fig. 1). Consequently three planned comparisons between the desktop interface and the PDA interface with PV for each condition of space type were calculated and revealed that in the Maze condition, the desktop interface drives to faster navigation times in comparison with the PDA interface under PV ($P < 0.05$); no other significant differences were observed between the interfaces in the other space type conditions.

From the *t* test analysis, a significant and a tendency to a significant difference between the desktop interface and the PDA interface was observed, respectively in the clustered area ($P < 0.05$) and narrow spaces ($P < 0.06$). We hypothesize that collected data were not significant due to an insufficient number of subjects.

Discussion

For data analysis, we considered finding a way through the maze an exploration task, driving alongside narrow spaces a navigation task, while driving in the clustered area a combination of both. The results show that the two interfaces are practically identical in the navigation task under the same condition of visibility (second experiment), a highly relevant distinction between them could be stated for the exploration task (first experiment). As predicted in the hypothesis section, already after 1.5 min of exploration the desktop exploration area was greater than the PDA one, and this difference gradually increased with time. The data analysis of the third experiment shows that in TV condition, the PDA interface results in a general better performance in terms of navigation times than the desktop interface independently from the space type; that is, the information the operator receives through the PDA, completed by the information he receives directly from the operating scenario, provides a better robot location and

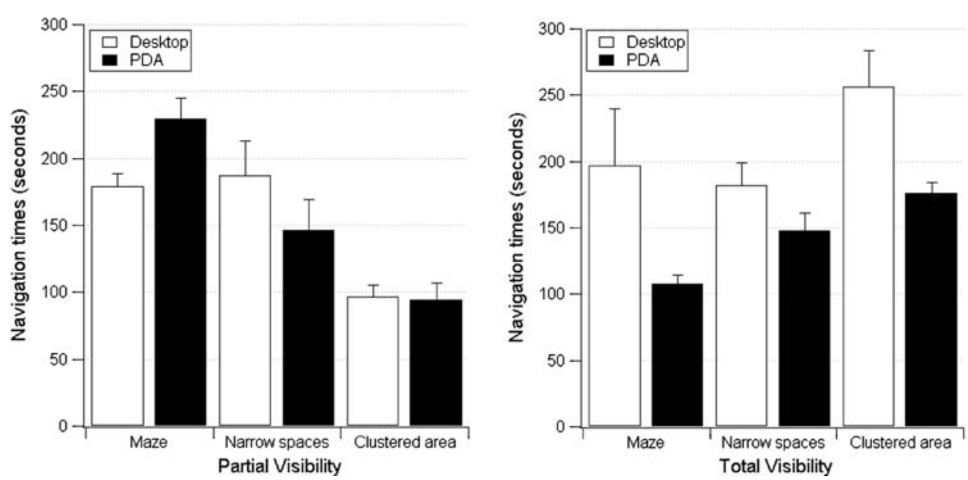

Fig. 1 Operator using PDA with partial visibility and full visibility of the scenario with respect to operator using desktop. Mean time and standard deviations are represented

surrounding awareness (Yanco et al. 2003). This implies that a PDA allows a successful task accomplishment when the robot is monitored using both screen given information and real environment cues. This different kind of information integration together with the interface simplicity allows to overcome the device limitations. Concerning the PV condition, the results indicate that an operator driving the robot with our desktop interface in a maze-like space, brings to faster navigation times than the operator using our PDA interface, probably due to the amount of information given by the two interfaces. Although in the desktop local and global (survey perspective—location awareness) and tridimensional (route—surrounding awareness) perspectives are simultaneously available, in the PDA only one of these views is shown and the operator must switch between tabs to change it, employing more time. This occurs mostly in mazes, presumably because in these kinds of environments a global configuration of the spatial structure (survey perspective) is needed in order to find a way out. This explanation is also supported by the *t* test results, which indicate a general better performance of our PDA interface in clustered and narrow spaces, which likely do not necessarily require survey knowledge to successfully navigate.

We finally claim that the differences between navigation and exploration are task-connected. We believe that all the information given by the desktop (local, global and tridimensional perspectives) is not necessary in the navigation task but indispensable in the exploration task, in order to give the required location awareness.

References

Cohen G (1989) In: Hove (ed) Memory in the real world. Erlbaum, Hillsdale

Drury JL, Keyes B, Yanco HA (2007) Lassoing HRI: analyzing situation awareness in map-centric and video-centric interfaces. In: Proceedings of the second ACM SIGCHI/SIGART conference on human–robot interaction, Arlington, Virginia, USA. ACM Press, New York, pp 279–286. ISBN:978-1-59593-617-2

Endsley MR (1988) Design and evaluation for situation awareness enhancement. In: Proceedings of the human factors society 32nd annual meeting, Anaheim, CA, USA. Human Factors and Ergonomics Society, Santa Monica, pp 97–101

Gerkey B P, Vaughan R T and Howard A (2003) The player/stage project: tools for multi-robot and distributed sensor systems. In 11th international conference on advanced robotics (ICAR 2003), Portugal, pp 317–323

Herrmann T (1996) Blickpunkte und blickpunktsequenzen. Sprache & Kognition 15:217–233

Nielsen CW, Goodrich MA (2006) Comparing the usefulness of video and map information in navigation tasks. In: Proceedings of the 1st ACM SIGCHI/SIGART conference on human–robot interaction, HRI 2006, pp 95–101

Olsen DR, Goodrich MA (2003) Metrics for evaluating human–robot interactions. In: Proceedings of PERMIS 2003

Scholtz J, Young J, Drury JL, Yanco HA (2004) Evaluation of human–robot interaction awareness in search and rescue. In: Robotics and automation, 2004. Proceedings ICRA 2004, vol 3. IEEE, May 2004, pp 2327–2332

Siegel A, White S (1975) The development of spatial representations of large-scale environments. In: Reese H (ed) Advances in child development and behavior, vol 10. New York, pp 9–55

Tversky B (1991) Spatial mental models. In: Bower G (ed) The psychology of learning and motivation, San Diego, pp 109–145

Yanco HA, Drury JL, Scholtz J (2003) Awareness in human–robot interactions. In: Proceedings of the IEEE conference on systems, man and cybernetics, Washington, DC, October 2003