Proceedings of the 2002 IEEE
International Conference on Robotics & Automation
Washington, DC • May 2002

ENHANCING A HUMAN-ROBOT INTERFACE USING SENSORY EGOSPHERE

CARLOTTA JOHNSON, A. BUGRA KOKU, KAZUHIKO KAWAMURA, and R. ALAN PETERS II
{johnsonc; kokuab; kawamura; rap2} @ vuse.vanderbilt.edu

Intelligent Robotics Laboratory, Vanderbilt University, Nashville, TN 37235 USA

Abstract

This paper presents how a Sensory EgoSphere (SES), a robot-centric geodesic dome that represents the short term memory of a mobile robot, could enhance a human-robot interface. It is proposed that the addition of this visual representation of the sensor data on a mobile robot enhances the effectiveness of a human-robot interface. The SES migrates information presentation to the user from the sensing level to the perception level. The composition of the vision with other sensors on the SES surrounding the robot gives clarity and ease of interpretation. It enables the user to better visualize the present circumstances of the robot.

The Human-Robot Interface (HRI) will be implemented through a Graphical User Interface (GUI) which contains the SES, command prompt, compass, environment map, sonar and laser display. This paper proposes that the SES increases situational awareness and allows the human supervisor to accurately ascertain the present perception (sensory input) of the robot and use this information to assist the robot in getting out of difficult situations.

Keywords
Sensory EgoSphere (SES), Intelligent Machine Architecture (IMA), Human-Robot Interface (HRI), Graphical User Interface (GUI), supervisory control, mobile robots

1 Introduction

In the IRL at Vanderbilt University, we are working with a team of heterogeneous mobile robots coordinated by a human supervisor to accomplish specific tasks. To successfully manage this, the supervisor needs a robust human-robot interface (HRI). The purpose of this research is that current HRI implementations through direct sensor feedback have a number of drawbacks. One disadvantage is that video communication requires a high bandwidth, video storage and high volume. Also, video storage may require a large amount of memory space. The history feature of the SES allows the user to replay the iconic representation of the sensory data. This is also an advantage in that typical mobile robots do not have 360 degrees of data. Another disadvantage in current implementations is that the user has difficulty in combining diverse sensory information to accurately determine the present surroundings of the robot. To overcome these drawbacks information presentation was translated to the user from the sensing level to the perception level. During its interaction with the world the robot perceives the environment and represents it in an egocentric manner. This representation is referred to as the Sensory EgoSphere (SES) [1]. This paper proposes that the SES allows the human supervisor to accurately ascertain the present perception (sensory input) of the robot and use this information to assist the robot in navigating out of difficult situations. A secondary use of the SES is that the user can correct perceptions of the world by viewing the SES to see misidentified or misplaced objects.

2 Graphical User Interface

A graphical user interface (GUI) is an interface used for the use of direct manipulation of icons or other graphical symbols on a display to interact with a computer [2]. A good user interface should be flexible and allow the user to change the methods for controlling the robot and viewing information as the need arises. A graphical user interface should reflect the perspective of the users. The most important aspect about a good graphical user interface is the ease of use and clarity. Figure 1 is the original GUI screen used for the mobile robots in this study.

Figure 1: Original GUI screen

The cognitive design approach applies theories of cognitive science and cognitive psychology. The theories state how the human perceives, stores and retrieves information from memory, then manipulates that information to make decisions and solve problems. In this design approach the human is regarded to be adaptive, flexible, and actively involved in interacting with the environment to solve problems or make decisions. This approach views human-computer interaction as presenting problems that must be solved by the operator [2].

The addition of the SES is a means of improving some of these features of GUI design. The SES will be flexible in that it can be seen from multiple views and the user has the option of selecting what information will be displayed. It is also a cognitive display in that it represents the short-term memory of the robot and displays it graphically. Figure 2 is the enhanced graphical user interface after the addition of the SES.

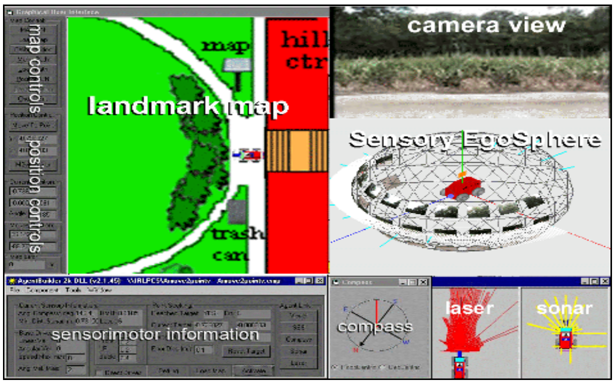
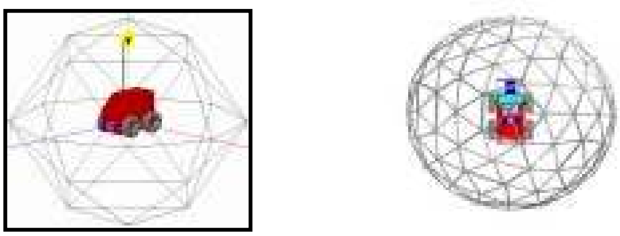


Figure 2: Enhanced GUI screen

The SES display will contain several views to assist the user. The default view is a worldview, with a panoramic view of the sonar, laser and camera data. Figure 3 shows the initial orientation of the SES as well as the geodesic SES representation.



(a) **(b)**

Figure 3a: Initial Orientation of the SES
3b: Geodesic SES Representation

3 The Sensory EgoSphere

An EgoSphere was first proposed by Jim Albus. In Albus' definition, the Sensor EgoSphere is a dense map of the world projected onto a sphere surrounding the robot at an instance of time [3].

In the Intelligent Robotics Laboratory, the Sensory EgoSphere is a 3D spherical data structure, centered on the coordinate frame of the robot, which is spatially indexed by azimuth and elevation. Its implicit topological structure is that of a geodesic dome, each node of which is a pointer to a distinct data structure. The SES is a sparse map of the world that contains pointers to descriptors of objects that have been detected recently by the robot. Figure 3b is an example of the representation of the SES and its position relative to the mobile robot.

The robot's perception of the world is represented by the SES and is directly reflected to the GUI screen. The composition of the vision with other sensors on the dome surrounding the robot gives clarity and ease of interpretation to the circumstances presently surrounding the robot as well as past sensory events in real time. The human supervisor communicates with the robot through the GUI screen, which contains the SES, mission-level commands, the environment map, laser display, sonar display and tele-operation commands (see Figure 1 and Figure 2).

Autonomous navigation can lead to problems and certain relative spatial configurations of robot and environment may result in the robot being unable to move.

The SES provides a useful display of all of the sensory modes to assist in the robot's present state. The SES also can provide a history of sensor events accessible by the user. This history of sensor events would assist the user in determining the current state of the robot. The SES would also eliminate the expensive video replay, which consumes a high bandwidth. Accurate remote control of the mobile robot would be facilitated by an intuitively understandable display of the robot's sensory information.

The resolution of the SES can be increased by a tessellation frequency to provide more discrete positions for posting sensory data. The SES represents a short-term memory database with objects posted to the vertices of the sphere that represent a pointer to data. The sonar and laser data are only located along the equator of the SES due to the hardware limitations. When the robot is stationary, it can fill the SES with data it senses. When the robot is mobile, the data will stream across the surface of the sphere dependent upon the velocity and orientation of the robot. A sensory data set of a specific type at a specific SES location can be stored as an object with a timer that indicates its age. Objects at a specific SES location can be deleted from the sphere after a period of time depending on the type of data or the arrival of new up-to-date sensory information can overwrite the older information at the same location. Some quick methods of checking the validity of the currently posted data on the egosphere and the current state of the world are essential [4].

The EgoSphere display will contain several representations to assist the user. The original representation is a worldview, with a panoramic view of the sonar, laser and camera data (see Figure 3). The second view accessible to the user is either an iconic representation of objects located by the robot's camera or actual images. Figure 4 shows the iconic representation of objects versus actual camera images.

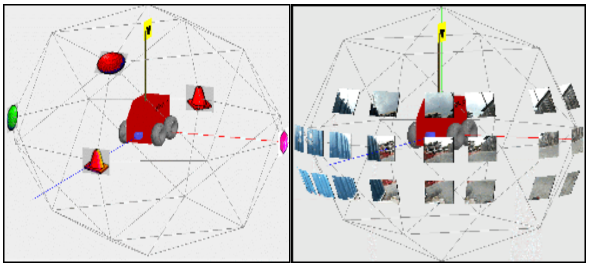


Figure 4: Iconic Objects and Camera Images

The SES also contains an egocentric view, which is more intuitive because it places the user in the robot's position. The camera view on the GUI can also be converted from nodal to a planetarium-like display which fills the dome with images from the camera. Figure 5 demonstrates both of these options.

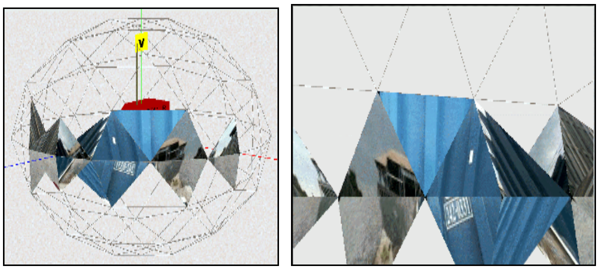


Figure 5: Planetarium View

The raw data from the sonar and laser sensors on the mobile robot can also be displayed on the SES. The initial view for this data is rays around the equator of the SES. This representation assists the user in visualizing the presence of objects or obstacles in proximity to the robot. These view options will be shown in the evaluation section.

4 Human-Robot Interface

In the enhanced Human-Robot Interface (HRI) proposed by this paper several agents communicate to relay information to the human supervisor. The Intelligent Machine Architecture (IMA) is an agent-based software architecture designed in the IRL. IMA defines several classes of atomic agents and describes their primary functions in terms of environment models, behaviors, tasks or resources. The resource agents are abstractions of sensor and actuator agents. The resource agents used for the human-robot interface are the camera, compass, laser, and sonar. It is proposed that the individual graphical representation of these agents does not provide the supervisor with a clear understanding of the present state of the robot. In order to combat this problem, the Sensory EgoSphere agent is integrated into the interface. The SES agent not only contains camera data but also renderings of the sonar and laser data. The consolidation of this data into one compact form facilitates the users access to a wide range of data.

Real time access to local sensor arrays, coupled with synthesized imagery from other databases (adapted from video-game technology and advanced visualization techniques), can also provide the user with a virtual presence in an area from a remote location, thereby aiding him in mission planning and other remote control tasks [5]. The SES presents a compact form of the display of various types of sensor arrays but is not sensory fusion. Sensory fusion develops a mechanism used to display various modes of sensory data in one mode.

The HRI is used to provide the human supervisor with the sensory information and present status of the mobile robot. The GUI developed for the HRI presents a wide range of information to the user. The information includes: a camera view, drive command, map of the world, calibration controls, sensor and motor status, laser, sonar and compass graphics. The data sent from the robot also includes current position and direction, and performance parameters.

The enhanced GUI will contain a Sensory EgoSphere agent that can be minimized, rotated and have the view changed. The SES will contain the second instance of certain data such as the camera, laser and sonar in a different viewing mode. In the future, the SES will also contain time stamps, history, robot speed and orientation and compass information. The SES display will also have the capability of being manipulated in order to change the focus of the robot's cameras. The enhanced GUI with the addition of the SES as previously illustrated in Figure 2.

5 Evaluation

The hypothesis is that the addition of the SES to the GUI will decrease the learning curve for the user to determine vital information about the mobile robot and its circumstances. The SES provides a more effective and efficient way to interact with the robot environment and understand the feedback from the robot sensors and interpretation of the world. This system is an improvement of a mobile robot interface that only provides instantaneous feedback from unassociated sensors.

The evaluation of this system was tested with several users. A command to autonomously navigate from point A to point B was given to the robot. The human supervisor is not consistently or constantly watching the robot progress. The robot sends a signal to the supervisor that an error has occurred and it is unable to complete the mission. In any system, errors are situations that cannot be avoided, thus it is necessary to have a status monitor to detect the errors that occur. The System Status Evaluation (SSE) resembles a nervous system in that it is distributed through most or possibly all agents in the system. By recording communication timing between agents, and by using statistical measures of the delay, an agent can determine the status of another agent [6].

Once the user receives the alert, the original GUI is opened and the user must determine the cause of the error. The user then uses the enhanced GUI with the several modes of the SES to find the state of robot.

The metric for the evaluation is a rating scale from 1 to 10. The higher the rating, the more the user was able to extract vital information from the sensor display. The users evaluated the agent displays of the camera, sonar, laser and SES graphic. This battery of tests was run twice, for an indoor and outdoor scenario. The two robot locations are shown in Figure 6.

Figure 6: Robot Evaluation Locations

In the first situation the robot encountered a three-way obstacle and was unable to navigate around it to reach point B. In the second location, the robot attempts to reach the destination but becomes immobile after veering off the walkway.

The test environment for the system evaluation enabled us to test the hypothesis that an enhanced GUI increases the user's situational awareness when at a remote location. The controlling variables are the Sensory EgoSphere and the GUI screen. The dependent variables are the time it takes the user to become familiar with the GUI and use it to extract key information. The assumption is that the addition of the SES decreases the learning curve as well as the difficulty in robot navigation remotely [1]. Users had to utilize the different components of the GUI and SES to devise a plan to recover the robot.

Figure 7 shows the various sonar and laser displays. Figure 7a is the default view of the laser and sonar data as rays emanating from the equator of the SES. Figure 7b is the ray display with connected endpoints to help the user envision the shape of the detected object. Figure 7c shows the sonar and laser data at the actual sensor location on the mobile robot. Figure 7d uses a three-dimensional cube to show the presence of an object.

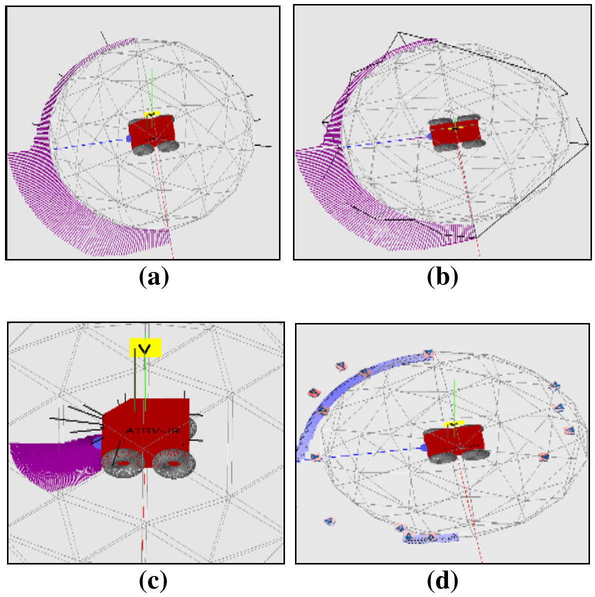


Figure 7: Sonar and Laser Display Modes

The second battery of evaluations studied the differences in the camera view on the GUI versus camera data on the SES. The users once again quantified how valuable each display was in assessing the state of the mobile robot. These optional views included a planetarium view, which placed the user inside the sphere with a robot-centric view. The iconic display provides an optional way to represent known landmarks in the robot's view. The final option placed images directly from the camera on the nodes of the SES. The images were placed on the node closest to the pan and tilt where they were found by the camera head. From the user responses, the SES components receiving the lowest ratings have been modified to increase their utility.

In the second phase of this research, users will be required to complete a task and rate how essential each display device was to accomplish the task by using the original GUI versus the enhanced GUI. The task will entail navigating the mobile robot through an obstacle course from point A to point B. The user will have an obscured view of the robot and will be completely dependent upon the camera view, sonar/laser display, compass, the environment map and the SES to complete the task.

6 Results

Users evaluating the enhanced GUI were approximately 70% undergraduate and 30% graduate engineering students. Most had a very general knowledge of robotics. In preparation for arrival of the evaluators, the robot was driven to a location hidden from the user (see Figure 6). The user was then placed in front of the original graphical user interface and asked to extract information about the robot's state based upon the camera view, sonar, laser and compass. The enhanced GUI was then opened and the user was asked the same questions by also using the SES and its various views on the interface. Users then ranked the camera, sonar and laser and SES views based upon the ability of the display to relay relevant and clear information.

These are preliminary results from the initial battery of evaluations. All but one instance of the addition of the SES enhanced the GUI. In the case of sonar and laser data posted to the equator of the SES, the ratings were actually worse for the enhanced GUI. It is hypothesized that the low result was caused by the planar view around the equator not being a realistic representation of how the sensors are placed on the robot. Other causes for this decline in response would be the display of the raw unfiltered data instead of removing values out of range and outliers. Due to this response, a three dimensional cubic representation was later added to the SES (see Figure 7). This view places a cube at the estimated position of detected objects as opposed to rays that are broken by obstacles. Future work will include removing all raw data and selecting a 3-D object, such as a sphere to denote object presence. Evaluation results are provided for the sonar and laser evaluation. A value of 10 denotes this particular sensor display on the SES provided additional information to the user to assist in determining vital information about the robot's state. The darker line shows the metric response for the original GUI for 10 different users. The sonar display on the SES had a 2.3% mean decrease in clarity for the enhanced GUI. The laser evaluation also had a mean of 13.5% decrease in clarity for the enhanced GUI. Figure 8 shows the sonar evaluation trend line.

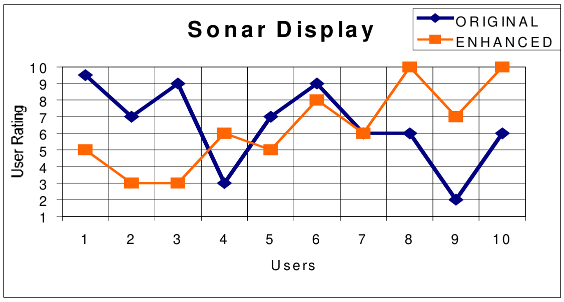


Figure 8: Sonar Evaluation Trend Line

Figure 9 shows the laser evaluation trend line.

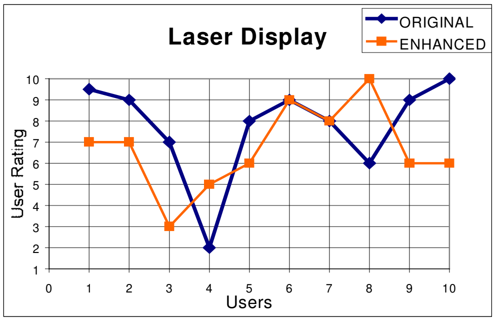


Figure 9: Laser Display Results

The camera view fared much better under the first stage evaluations and had an increase over the original GUI of 22% for icons on the nodes. The planetarium/egocentric view of the camera data also increased by a 20% increase in clarity. This could be attributed to the fact that viewing various images on the SES enables the user to see three-dimensionally the robot environment. In the future, the user will have the option to replay a history of SESs. This may provide details about the cause of the robot's distress signal. See Figures 10 and 11 for the overall user's response for the original GUI versus the enhanced GUI camera display results.

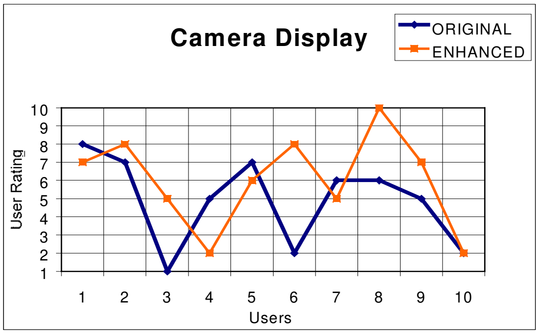


Figure 10: Nodal Camera Display Results

After the evaluation of preliminary test results and user comments about the camera display, there were also modifications made to this view as well. Some of the changes were to add a perspective view that reflected closer objects larger than objects further away. There was a zoom feature added along with keyboard accelerators to assist the more experienced user.

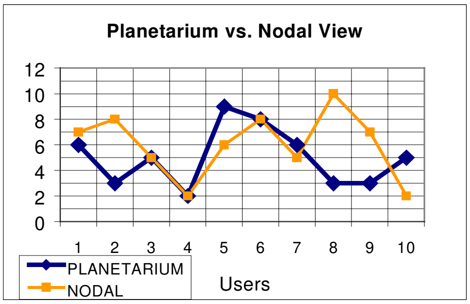


Figure 11: Planetarium Camera Display Results

7 Conclusion

The robot has a spatially organized, short-term memory called the SES, that associates various sensing modalities and greatly simplifies the task of maneuvering a robot out of a trapped position. The objects on the SES also present a means for the supervisor to give the robot commands qualitatively, rather than using the traditional quantitative methods. This paper proposes that presenting the robot's perspective to the human supervisor enhances the human-robot interface.

The experiments show that the addition of a Sensory EgoSphere enhances the usability of a graphical user interface. The evaluations have highlighted some areas that still need improvement, such as the sonar and laser display, but overall it shows that a more compact view of sensory data does aid in visualizing robot state.

8 Future Work

In the future, the SES will be modified to include clickable icons to view more detail as well as to add user-defined objects to the SES. It is also planned that the Sensory EgoSphere will be used in a project to develop an adaptive human-robot interface. This project will involve the robot taking the initiative to update the graphical user interface dependent upon the context of the task. The HRI will also be adaptable to user preferences. The SES will be a user interface component that has the options of resizing, minimizing, altering views and change display options of sensory data. The SES will also be an adaptable component of the HRI that will update or have its properties modified dependent upon the context of the robot mission and/or the user preferences.

Also planned for the future, the data on the SES will be tied to a database called the SES Database that will be indexed by pan and tilt. The user will then have the capability of clicking on a node on the graphical SES and viewing database data about objects posted to particular nodes as well as zooming in on the image.

The next battery of evaluations will use members of the general public to evaluate the enhanced GUI. This examination will include a spatial reasoning test to categorize users by their levels of understanding of relationships of objects in space. This second set of users will actually operate the mobile robot and observe results on the GUI screen and the SES graphic. Users will be given a task to complete with the robot using both the original and the enhanced GUI. It has been proposed that the addition of this SES will greatly enhance the user's situational awareness of the robot's circumstances. This enhanced GUI will offer users the opportunity to have a heightened presence in the robot environment.

Acknowledgements

This work has been partially funded through a DARPA-SPAWAR grant (Grant # N66001-01-1-8911NAVY). Additionally, we would like to thank the following IRL students: Phongchai Nilas, Turker Keskinpala and Jian Peng.

References

1. K. Kawamura, R. A. Peters II, C. Johnson, P. Nilas, S. Thongchai, Supervisory Control of Mobile Robots Using Sensory EgoSphere, IEEE International Symposium on Computational Intelligence in Robotics and Automation, Banff, Canada, pp. 531-537, July 2001.

2. J. A. Adams, Human Management of a Hierarchical System for the Control of Multiple Mobile Robots, Ph.D. dissertation, Computer and Information Science, University of Pennsylvania, Philadelphia, PA, 1995.

3. J. A. Albus. Outline for a Theory of Intelligence. IEEE Transactions on Systems, Man, and Cybernetics, v. 21(3), pp.473 – 509, May/June 1991.

4. A. B. Koku, R.A. Peters II, A Data Structure for the Organization by a Robot of Sensory Information, 2nd International Conference on Recent Advances in Mechatronics, ICRAM '99, Istanbul, Turkey, May 24-26, 1999.

5. J.L. Paul, Web-Based exploitation of Sensor Fusion for Visualization of the Tactical Battlefield, IEEE AESS Systems Magazine, pp. 29-36, May 2001.

6. K. Kawamura, D.M. Wilkes, S. Suksakulchai, A. Bijayendrayodhin, K. Kusumalnukool. Agent-Based Control and Communication of a Robot Convoy, 5th International Conference on Mechatronics Technology, Singapore, June 2001.