Enhancing a Human-Robot Interface Using Sensory EgoSphere

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March 29, 2002

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Introduction: Problem Statement

- In supervisory mobile robot control, it is often necessary for a human supervisor to teleoperate or observe a team of mobile robots.
- To effectively supervise the mobile robot, the supervisor must have a clear understanding of the present robot status and environment.

Introduction:
Problem Statement cont.

- The display of various sensory data from the mobile robot fills the interface screen and may tend to overwhelm the user.
- The disparity of the information as well as the modes of viewing may make it extremely difficult to mentally consolidate the information in order to make decisions concerning tasks and the environment.

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Human-Robot Interfaces: Human-Robot Ratios

Humans	Robot
One person	One Robot
One person	Many Robots
Many people	One Robot
Many people	Many Robots

[Murphy et al., 2001] Murphy, Robin R. and Rogers, E. “Human-Robot Interaction” Final Report for DARPA/NSF Study on Human-Robot Interaction. California Polytechnic State University. http://www.csc.calpoly.edu/~erogers/HRI/HRI-report-final.html, September 29, 30, 2001.

Human-Robot Interfaces: Authority Relationships

Human	Type of Control	Function	Context Required
Supervisor	Supervisory	Commands what	Tactical situation
Operator	Tele-operation	Commands how	Detailed perception
Peer	Mixed-Initiative	Cross cueing	Shared environment, functions

[Murphy et al., 2001] Murphy, Robin R. and Rogers, E. "Human-Robot Interaction" Final Report for DARPA/NSF Study on Human-Robot Interaction. California Polytechnic State University. http://www.csc.calpoly.edu/~erogers/HRI/HRI-report-final.html, September 29, 30, 2001.

Human-Robot Interfaces: State of the Art

- Natural Language
- Sensor Fusion
- Virtual Reality
- Telepresence
- Adaptive
- Applications
  - Aviation
  - Military
  - Space

Human-Robot Interfaces: Examples

- PdaDriver
- GestureDriver
- HapticDriver

Fong, T., Conti, F., Grange, S., and Baur, C. “Novel interfaces for remote driving: gesture, haptic and PDA” SPIE Telemanipulator and telepresence VII, Boston, MA, November 2000.

CONTENTS

Survey of HRI Evaluation Criteria

- Measured Attributes
  - Machine Intelligence Quotient (MIQ)
  - Situational Awareness
  - Mental Workload
  - Usability
- Methods
  - NASA TLX
  - Heuristic Evaluation
  - Cognitive Walkthrough
  - Contextual Inquiry
  - Spatial Reasoning
  - MUSiC

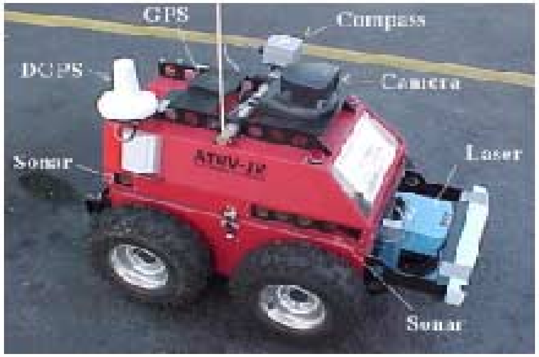
CONTENTS

Sensors for Mobile Robots

- Laser
- Sonar
- Vision
- GPS/DGPS
- Compass
- Odometry
- Gyroscope

Sensors for Mobile Robots

- Laser
  - An ultrasonic sensor introduces acoustic energy into the environment and measures the time of flight of the signal to return.
- Sonar
  - measures the time between the initiation of a ping and the return of its echo.
- Vision
  - computer vision is used to understand the scene that an image depicts



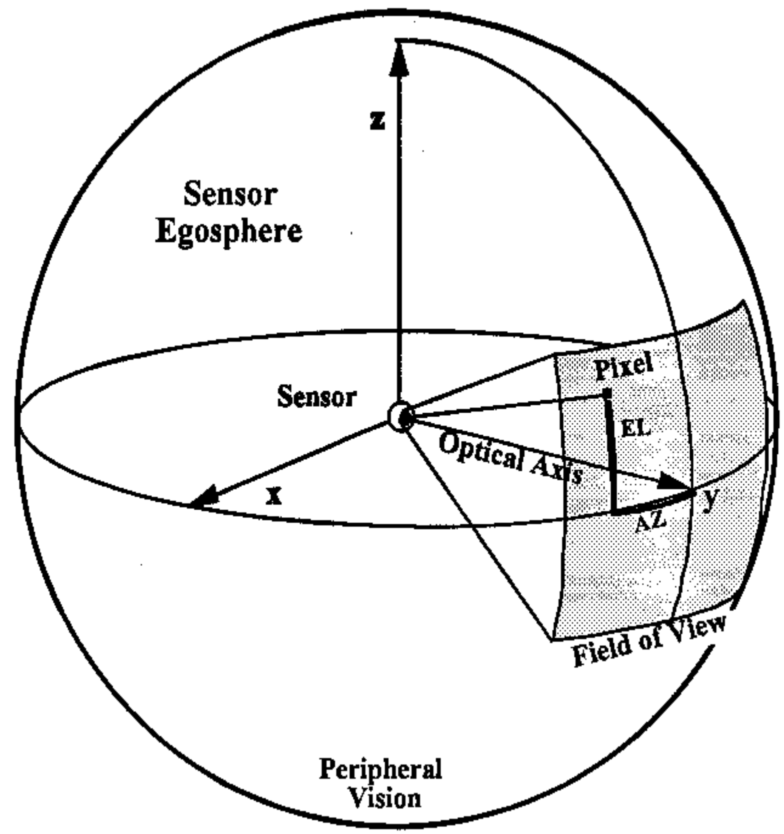
ATRV-JR

Modified Pioneer2

CONTENTS

Sensor EgoSphere

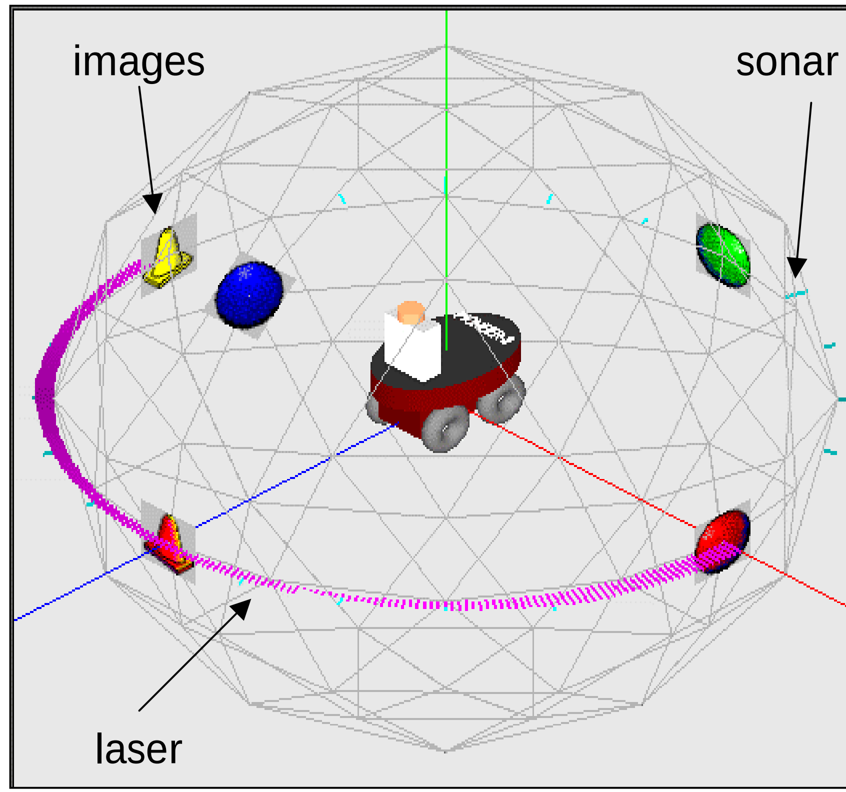
- Jim Albus defined the Sensor EgoSphere as a two-dimensional dense spherical map coordinate system with the self (ego) at the origin
- Visible points on regions or objects in the world are projected on the egosphere wherever the line of sight from a sensor at the center of the egosphere to the points in the world intersects the surface of the sphere
- Real-time sensory data can be used to build world maps and give a user a world model.



Albus, J.A., Engineering of Mind: An Introduction to the Science of Intelligent Systems, August 2001, John Wiley & Sons, New York.

Sensory EgoSphere (SES) for Mobile Robots

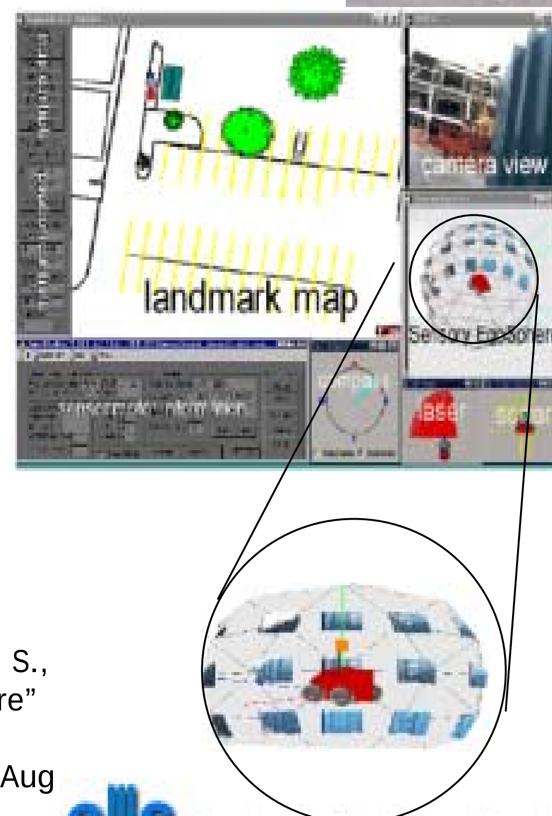
- Alan Peters redefined the Sensory Egosphere as a sparse spatiotemporally indexed short term memory (STM)
- Structure: a variable density geodesic dome
- Nodes: links to data structures and files
- Indexed by azimuth, elevation and time
- Searchable by location and content



Peters, R. A. II, K. E. Hambuchen, K. Kawamura, and D. M. Wilkes, "The Sensory Ego-Sphere as a Short-Term Memory for Humanoids", Proc. IEEE-RAS Int'l. Conf. on Humanoid Robots, pp. 451-459, Waseda University, Tokyo, Japan, 22-24 Nov. 2001.

Applications of the SES: Supervisory Control

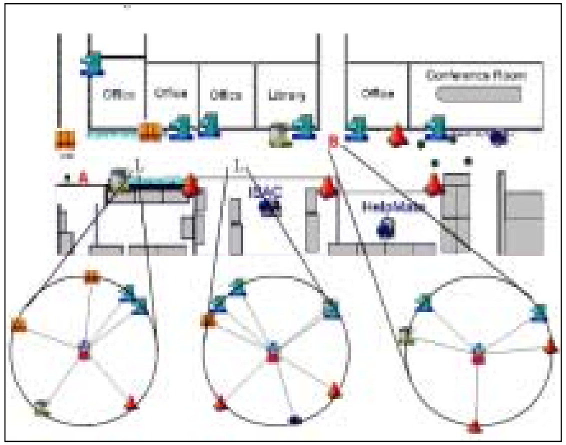
- In supervisory control scheme, a person gives high level commands to a mobile robot, which then proceeds autonomously
- Autonomous navigation can lead to problems, however. The robot may at times be unable to complete a given task autonomously and need supervisory intervention.
- intuitive user-friendly displays would assist a supervisor in resolving a situation

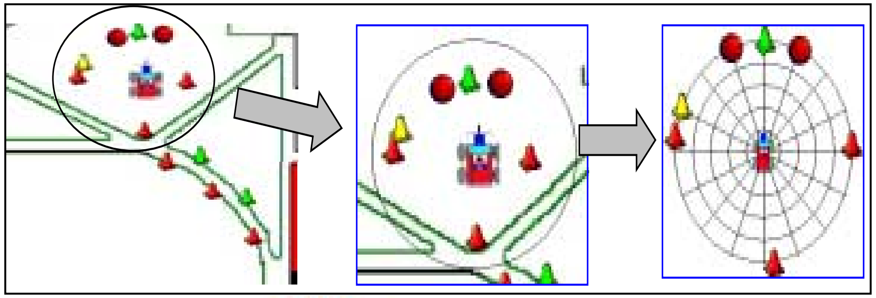


Kawamura, K., Peters II, R.A., Johnson, C., Nilas, P. and Thongchai, S., "Supervisory Control of Mobile Robot using Sensory EgoSphere" Proceedings of 2001 IEEE International Symposium on Computational Intelligence in Robotics and Automation (July/Aug 2001):523 – 529.

Applications of the SES: Range-Free Perception-Based Navigation

- Perception-based navigation is an approach where the robot uses via points to define via regions.
- Regions are where the robot can navigate reactively
- The SES is an egocentric map that the robot uses to locate itself in a region
- 2D Ego Circle





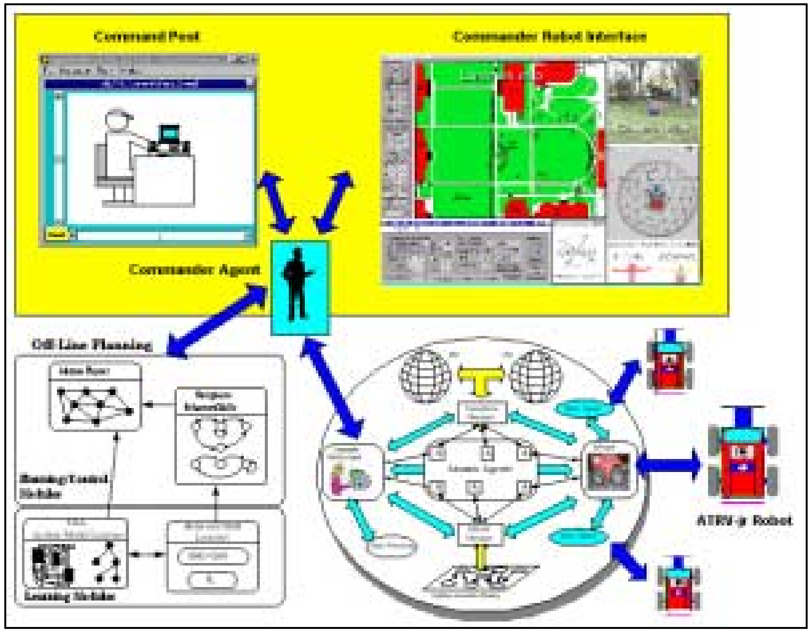
Kawamura, K., Peters II, R.A., Wilkes, D.M., Koku, A.B., and Sekmen, A. “Toward Perception-Based Navigation using EgoSphere” Proceedings of SPIE, Intelligent Systems and Advanced Manufacturing (ISAM 2001)

CONTENTS

- Introduction
- Human-Robot Interfaces
- Evaluation of Human-Robot Interfaces
- Sensors for Mobile Robots
- Sensory EgoSphere (SES) for Mobile Robots
- IMA-based GUI
- Research Proposal

IMA-based GUI: HRI for Mixed Initiative Control

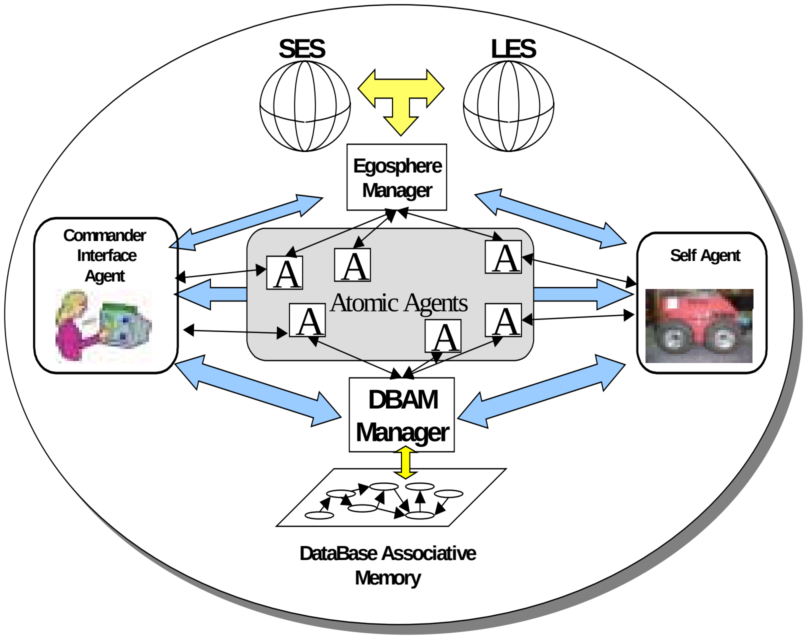
- includes the graphical user interface, off line mission planning agent and the user command post.
- present information to the robot as well as the robot must present information to the user in a way that is easy and quick to interpret.
- information must be gathered from distributed sources and filtered for relevant content to the current stage of the mission



Johnson, C.A., Koku, A.B., Kawamura, K. and Peters II, R.A. "Enhancing a human-robot interface using Sensory EgoSphere" Accepted to ICRA 2002 (May 2002).

IMA-based Robot Control Architecture

- includes a SES, LES, Self (Robot) Agent, Commander Interface Agent, EgoSphere Manager, Database Associative Memory (DBAM) and DBAM Manager.
- Two compound agents
  - commander interface agent
  - robot agent.



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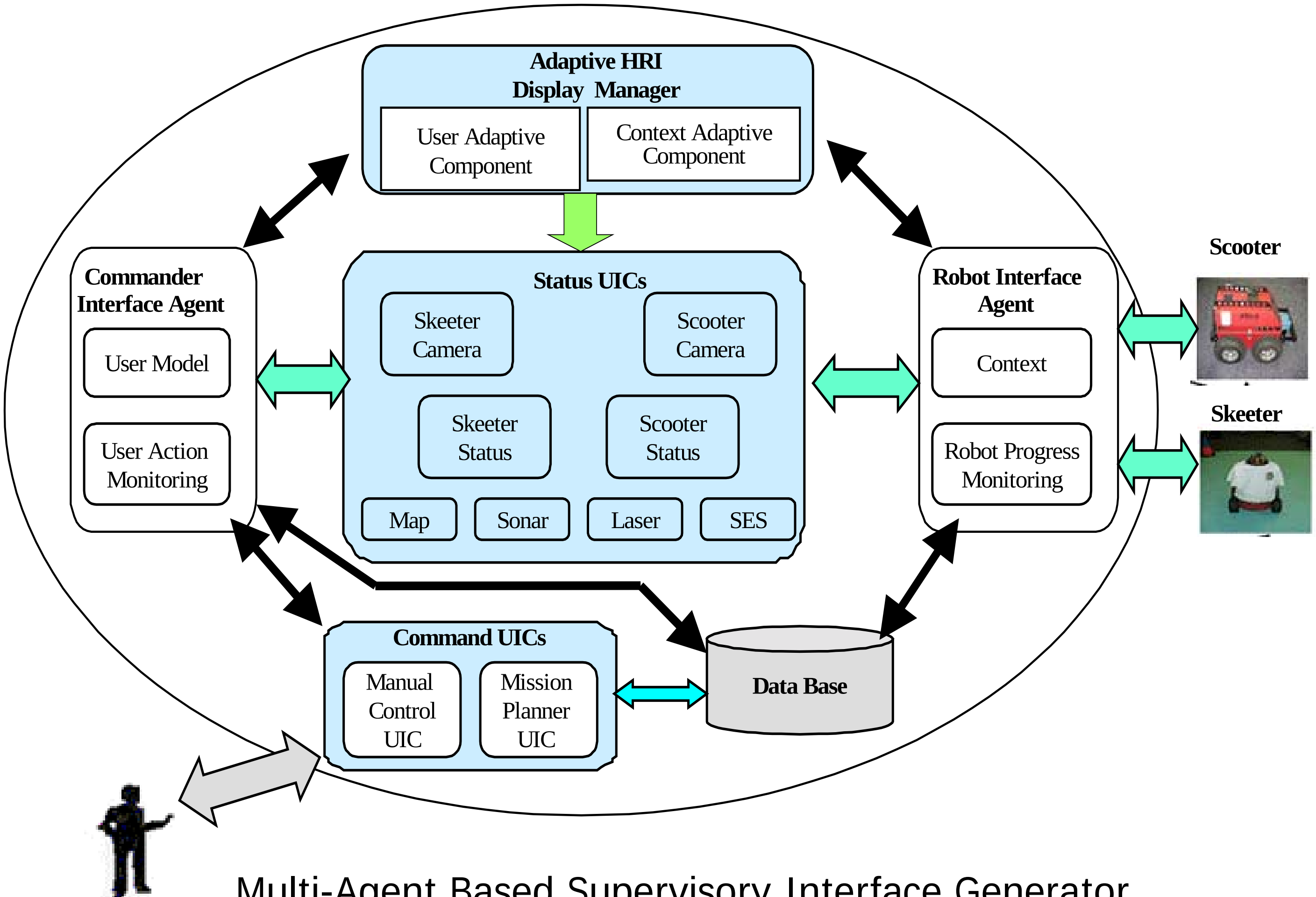
Research Proposal: Research Goal

To develop a more effective and efficient robot user interface based upon an agent-based human-robot interface with the addition of a Sensory EgoSphere.

Research Proposal: Research Hypotheses

- The SES will decrease user cognitive workload with the addition of a more intuitive display of sensory data
- The SES will increase user situational awareness of the robot status and task/mission status
- The SES can be used for mixed-initiative control by detecting an object of interest and initiating a behavior based upon the discovery

Research Proposal

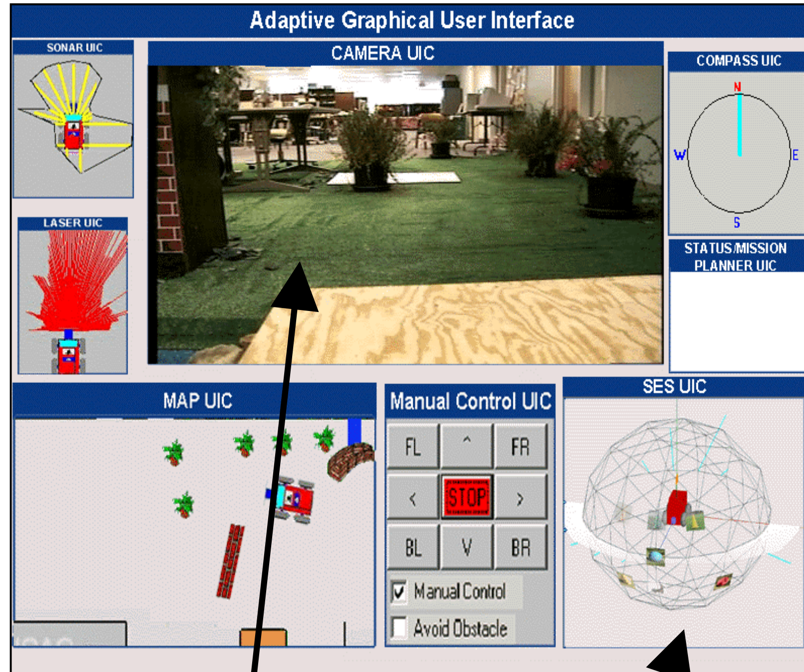


Multi-Agent Based Supervisory Interface Generator

Nilas, Phongchai. “Tools and Techniques for Adaptive Human-Robot Interface”, Area Paper, Electrical and Computer Engineering, Vanderbilt University, 2002.

Research Proposal: GUIM

- performs GUI updates and adjusts the interface component's parameters to reflect the operation stage.
- handles query arbitration and dispatches between the human and the robot.
- two components
  - User Adaptive Component
  - Context Adaptive Component.
- three standard user profiles:
  - novice
  - intermediate
  - expert
- user interface components (UIC) enable the human to view relevant data about the robot's current status and mission.



Camera UIC - detect objects of interest

The SES UIC- view current state of the robots

Research Proposal: SES Agent / Manager

- communicates with the other available interface agents.
- controls what information is sent to the SES agent and graphically displayed to the user.
- receive information from the graphical user interface manager, such as orientation, zoom and view options of data.
- handle all the read and write request form other agents to the SES database
- sensory processors will also write information to the SES database.
- put a time stamp on all objects posted to the nodes of the egosphere.

Research Proposal: User Groups

- NOVICE
  - University students (non-engineering, science)
- EXPERTS
  - area robotics researchers

Research Proposal: Experiments/Testbed

HYPOTHESES	SCENARIO	TASK
Cognitive Workload	1 •	Tele-operate the robot from point A to point B avoiding obstacles and the enemy
Situational Awareness	2 •	Supervise the robot perform an autonomous task and extract robot/mission status
Mixed-Initiative Control	3 •	Tele-operate the robot while the robot searches for the enemy

Research Proposal: Evaluations

- Vandenberg Mental Rotation Test
- Pre-Experiment Survey
- Post-Task Survey
- Post-Experiment Survey
- Contextual Inquiry
- NASA-TLX Questionnaire

Research Proposal: Methods of Data Collection

HYPOTHESES	SCENARIO	Method
Cognitive Workload	1	NASA – TLX Videotape Time to complete task
Situational Awareness	2	Contextual Inquiry Questions during task execution
Mixed-Initiative Control	3	Contextual Inquiry

Research Proposal: Expected Results

- Develop an enhanced HRI with mixed-initiative control
- Conduct experiments and evaluate the current
- Enhanced HRI will be shown to decrease the task execution time for a given user
- User Situational Awareness will increase
- User Cognitive workload stress will decrease

Research Proposal: Schedule Milestones

DELIVERABLE	DATE
SES Graphic	April 30, 2002
SES Agent	May 15, 2002
GUI Manager	June 30, 2002
Final Experimental Design	July 15, 2002
Data Collection	September 15, 2002
Data Analysis	October 30, 2002
Dissertation to Committee	November 15, 2002

Questions

?

Introduction:
Taxonomies for Human-Robot Interaction

Role	Human's point of view	Spatial Relationship
Commander	God's eye	Remote
Peer	Bystander	Beside
Teleoperator	Robot's eye	Robo immersion
Developer	Homunuculus	Inside

Human-Robot Interfaces: Types of Control

- Direct
  - operates the remote vehicle using hand-controllers while monitoring a video
- Autonomous
  - The human gives a high-level, abstract goal which the robot then achieves by itself.

Human-Robot Interfaces: Types of Control. (cont.)

- Supervisory
  - Human gives high-level goals or tasks to the robot, which independently achieves them.
  - Once the human has given control to the robot, he supervises
- Mixed-Initiative
  - The robot has the option of asking the human to assist where needed.
  - the human supplements automation in order to compensate for inadequacies.

Novel Interfaces: Hands-free control (Slide 1)

- Hands free device to control a mobile robot
- Brainwave control has been successfully demonstrated by other researchers in a variety of fields.
- Control direction with jaw movements
- Control speed with brain wave amplitude
- The Mindmouse input device with electrode headband was used to translate data into mobile robot commands.

Amai, W., Fahrenholtz, Jill C. and Leger, C. "Hands-free Operation of a Small Mobile Robot" IEEE Workshop on Vehicle Teleoperation Interfaces, San Francisco, April 2000.

Novel Interfaces: Three-dimensional PC

- 3D display that does not require stereo glass to present a 3D GUI

- A natural and intuitive user interface takes advantage of human propensities and physical analogies with familiar devices

[Liu et al., 2000] Liu, J. Pastoor, S., Seifert, K. Hurtienne, J. "Three-dimensional PC: toward novel forms of human-computer interaction" Three-Dimensional Video and Display: Devices and Systems SPIE CR76, 5-8 Nov. 2000 Boston, MA USA

Novel Interfaces: Line of Sight Camera Control

- A user can control the aspect of a multifunction-monitoring camera using only his LOS.
- Three LOS parameters: fixed gaze, shifting LOS and disinterest.
- Fixed gaze is the zoom
- Shifting the gaze changes the area of focus
- When the LOS is not focused, the camera zooms out to default magnification

Nishiuchi, S., Kurihara, K., Sakai, S. and Takada, H. “A Man-Machine Interface for Camera Control in Remote Monitoring Using Line-of-Sight”

Applications: Aviation

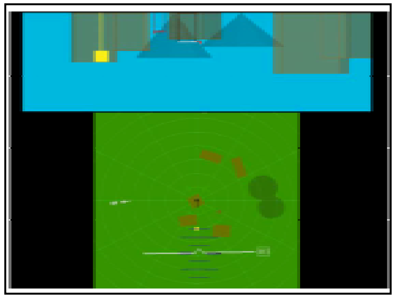
- Studies conducted done on three prototype displays to determine the benefit for aircraft navigation and tactical hazard awareness;
  - a conventional 2D coplanar display
  - an exocentric 3D display
  - an immersed 3D display.

- These viewpoints serve three categories of tasks of spatially relevant aviation tasks,
  - local guidance
  - navigational checking
  - spatial or hazard awareness.

[Wickens et al., 1997]Wickens, C.D., Olmos, O., Chudy, A. and Davenport, C. "Aviation Display Support for Situation Awareness", University of Illinois Institute of Aviation Technical Report (ARL-97-10/LOGICON-97-2). Savoy, IL: Aviation Res. Lab. 1997

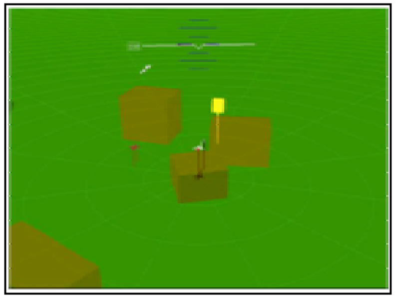
Applications: Aviation (cont.)

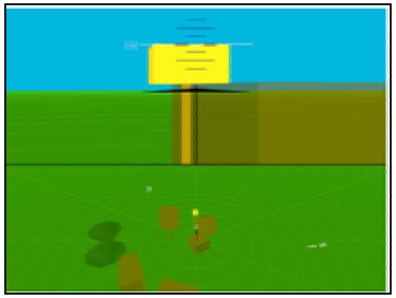
- 3D displays appear to be the most beneficial for guidance tasks and for navigational checking.
- immersed view appears to be inferior as a means of providing hazard awareness information.
- The differences between coplanar and exocentric are more subtle.



2D Coplanar Display

3D Exocentric Display





Split Screen: The upper screen is the 3D Immersed Egocentric Display

Wickens, C.D., Olmos, O., Chudy, A. and Davenport, C. "Aviation Display Support for Situation Awareness", University of Illinois Institute of Aviation Technical Report (ARL-97-10/LOGICON-97-2). Savoy, IL: Aviation Res. Lab. 1997

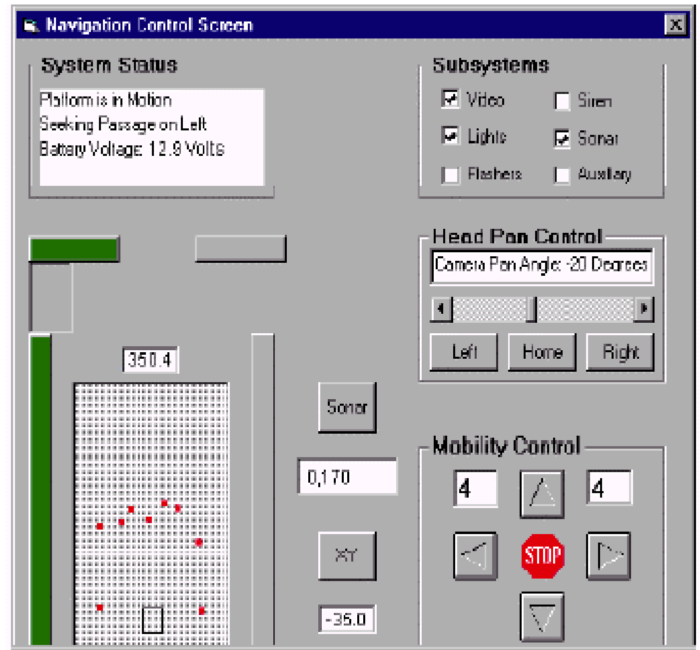
Applications: Military

- In military applications, the realm of coordinated weapons control is extended by reflexive tele-operation.
- The man-machine interface for this application is divided into three general categories: mobility control, camera control and non-lethal weapons control
- The interface, the mobility control window provides a convenient means for the operator to set the desired speed and if necessary manually change the platform's heading.

Gilbreath, G.A., Ciccimaro, D.A. and Everett, H.R., "An Advanced Telereflexive Tactical Response Robot," Autonomous Robots, Vol. 11, No. 1, 2001.

Applications: Military (cont.)

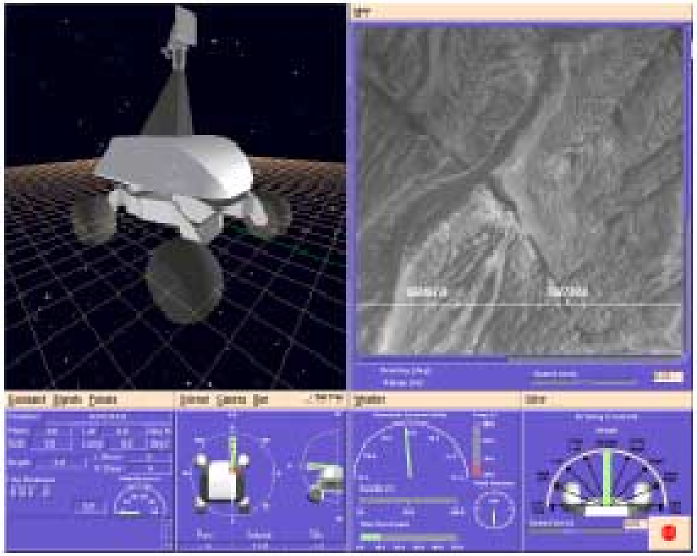
- control subsequent action by clicking on special behavioral icons, depicted on the navigation display.
- the wall-following icon or the doorway icons are behavior icons
- manual camera control using the slider and button control
- camera has three system functionalities:
  - platform mobility
  - intruder assessment
  - weapons tracking



Gilbreath, G.A., Ciccimaro, D.A. and Everett, H.R., “An Advanced Telereflexive Tactical Response Robot,” Autonomous Robots, Vol. 11, No. 1, 2001.

Applications: Space Exploration (cont.)

- novice drivers used the keyboard bindings the most
- novice drivers also seemed to over steer the vehicle when driving at top speeds.
- experienced drivers made greater use of the compass, position, and pitch and roll



Wettergreeen, D., Bualat, M., Christian, D., Schwehr, Thomas, H., Tucker, D. and Zbinden, E., "Operating Nomad During Atacama Desert Trek", Field and Service Robotics Conference, Canberra, Australia, 1997.

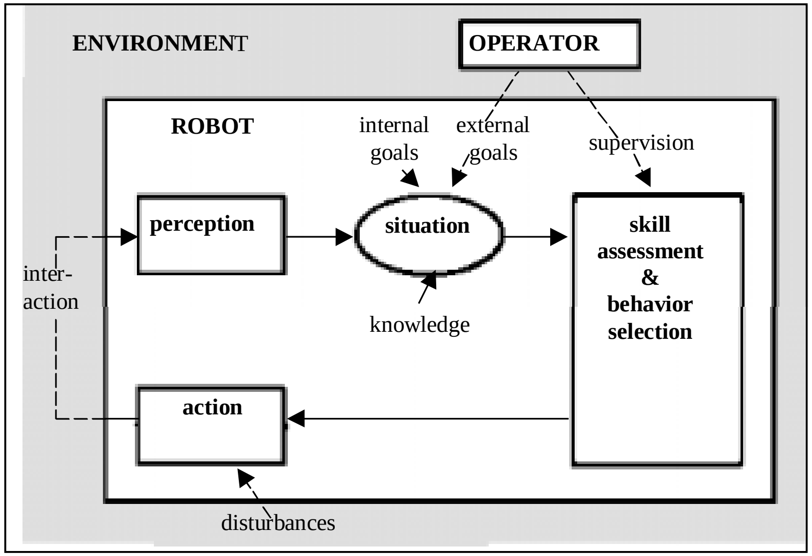
Evaluation of HRI: Machine Intelligence Quotient (MIQ)

- a new index to represent machine intelligence
- the process of analyzing, organizing, and converting data into knowledge
- divided into control intelligence and interface intelligence
- designed with a human orientation so the MIQ represents the degree of machine intelligence close to what the user feels
- uses the mental workload (MWL) in the measurement procedure to reflect human factors

Park, H., Kim, B., and Lim, K. "Measuring the Machine Intelligence Quotient (MIQ) of Human-Machine Cooperative Systems", IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, Vol. 31, No. 2, March 2001.

Evaluation of HRI: Situational Awareness

- Situational awareness is defined as the knowledge of what is going on around the human operator or the robot.
- three levels
  - perception
  - comprehension
  - prediction



Graefe, V. "Perception and Situation Assessment for Behavior-Based Robot Control." Intelligent Autonomous Systems, Kakazu, Y., Wada, N., Sato, T., Editors, Amsterdam: IOS Press, 1998, pp. 376-383.

Evaluation of HRI: Mental Workload

- a measurable quantity of the information processing demands placed on an individual by a task.
- consists of objective factors such as number of tasks, urgency, and cost of non-completion of task on time or correctly
- consists of subjective factors and environmental variables.
- cognitive workload relates to the mental effort required to perform tasks.

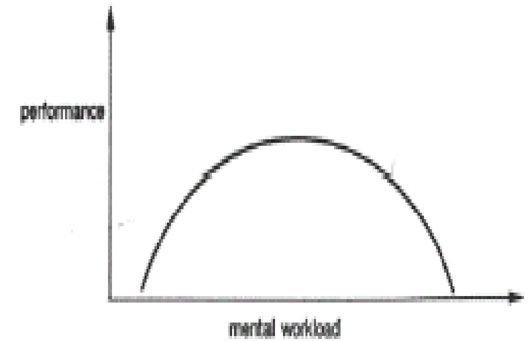


Figure 46: Relation of Performance to Workload (from [Sheridan 93])

Bevan, N. "Measuring usability as quality of use", Journal of Software Quality Issue 4, pp 115-140, 1995.

Evaluation of HRI: Usability

the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

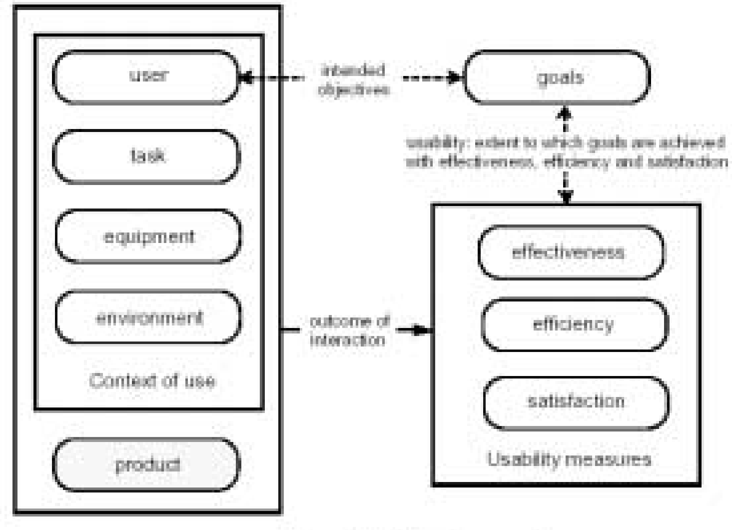


Figure 1 Usability framework

Bevan, N., Kirakowski, J., and Maissel, J. "What is Usability?" Proceedings of the 4th International Conference on HCI, Stuttgart, September 1991.

Evaluation of HRI: Evaluation Schemes NASA TLX

- a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales.
- Three subscales relate to the demands imposed on the subjects in terms of:
  - the amount of mental and perceptual activity required by the task;
  - the amount of physical activity required by the task;
  - the time pressure felt due to the task.
- Three subscales relate to the interaction of an individual with the task:
  - the individual's perception of the degree of success;
  - the degree of effort an individual invested;
  - the amount of insecurity, discouragement, irritation and stress.

Adams, J.A. "Human Management of a Hierarchical System of the Control of Multiple Mobile Robots." Ph.D. thesis, Computer and Information Science, University of Pennsylvania, 1995.

Evaluation of HRI: Evaluation Schemes Heuristic Evaluation

Heuristic evaluation involves having a group of interface evaluators examine an interface and look for violations of interface design principles.

Heuristic Evaluation is essentially a process of applying 'golden rules' of effective interface design to a target IS. The evaluation process involves walking through the interface, assessing which aspects of the interface are in agreement with these rules.

Prothero, J. "A Survey of Interface Goodness Measures."March 16, 1994, HITL Technical Report R-94-1. http://www.hitl.washington.edu/publications/r-94-1/r-94-1.pdf.

Evaluation of HRI: Evaluation Schemes Measuring Usability of Systems in Context (MusiC)

- MusiC is a set of evaluation methods analytic and user-based from which evaluators can choose to adopt methods individually or in combination to measure those aspects which they (or the developers or procurers) consider most important.

- Significant outputs of MusiC include the usability context analysis method and guide

Bevan, N. and Curson, I. "Methods for Measuring Usability", Proceedings of the sixth IFIP conference on human-computer interaction, Sydney, Australia, July 1997.

Evaluation of HRI: Evaluation Schemes Cognitive Walkthrough

- a theory-based usability evaluation approach that attempts to use a theory of learning by exploration in a manner akin to a programming walkthrough

- consists of answering a set of questions about each of the decisions which an interface user must make, and rating the likelihood that the user will make an incorrect choice

Wild, P.J., and Macredie, R.D. “Usability Evaluation and Interactive Systems Maintenance”, Paris, C., Howard, S., and Ozkan, N. (Eds). OZCHI'2000, Sydney.

Evaluation of HRI: Evaluation Schemes Cooperative Evaluation (Contextual Inquiry)

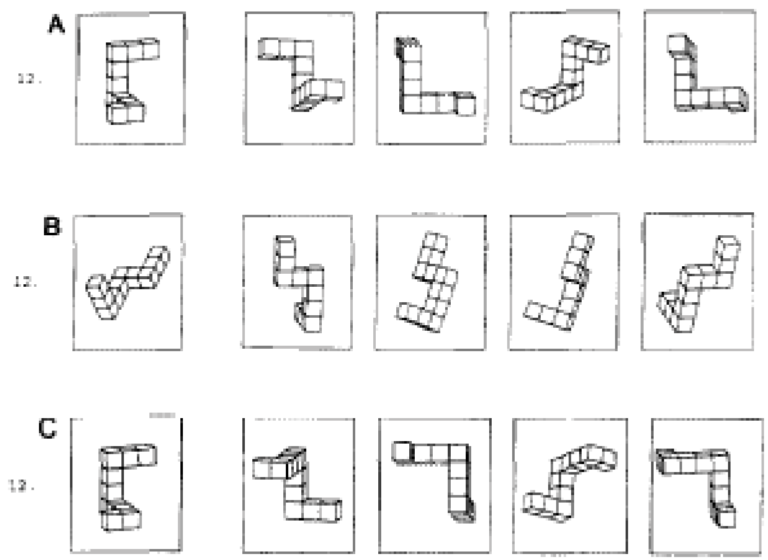
- think-aloud observational technique
- demands an initial task decomposition
- a structured interviewing method for grounding the design of interactive systems in the context of the work being performed
- appropriate for qualitative system assessment, rather than for performance measurement.

Fong, T. "Collaborative control: A Robot-Centric model for Vehicle Teleoperaiton." Ph.d. thesis, The Robotic Institute, Carnegie Mellon University, Pittsburgh, PA. November 2001.

Evaluation of HRI:
Evaluation Schemes Spatial Reasoning

Designed to measure the time it takes a subject to determine if two shapes are identical except for an angular difference in the portrayed orientations of the two three-dimensional objects.

Vandenberg Mental Rotation Test is the most common.



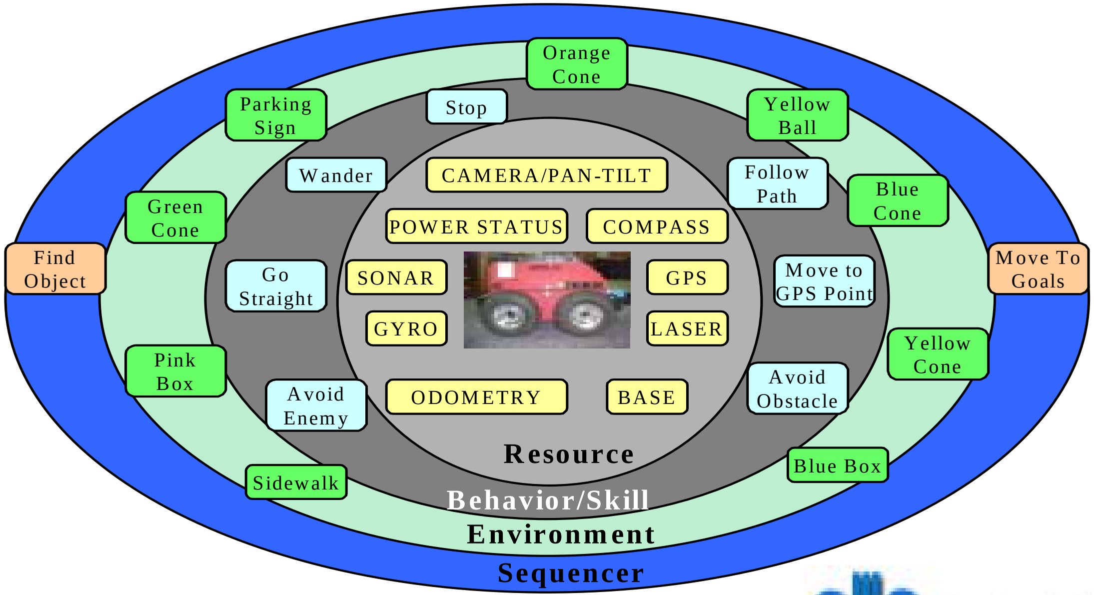
Vandenberg, S.G. and Kuse, A.R. “Mental Rotation: A group test of three dimensional spatial visualization.” Perceptual and Motor Skills, vol. 47, 1979, pp. 599 – 604.

IMA-based GUI

- The Intelligent Machine Architecture (IMA) is an agent-based software architecture designed in the IRL.
- IMA provides a means for developing software agents that communicate in a distributed environment
- The five types of atomic agents are: hardware/resource, behavior/skill, environment, sequencer, and multi-type
- The SES primarily communicates with the sensor and actuator agents which provide abstractions of sensors and actuators and incorporate basic processing and control algorithms

A GUI Based on IMA

- Current Graphical User Interface can be divided into the hardware interface and the IMA agent
- Resource agents are the base, odometry, sonar, laser, GPS, DGPS, compass, and power
- Behavior agents are avoid-obstacle, avoid-enemy



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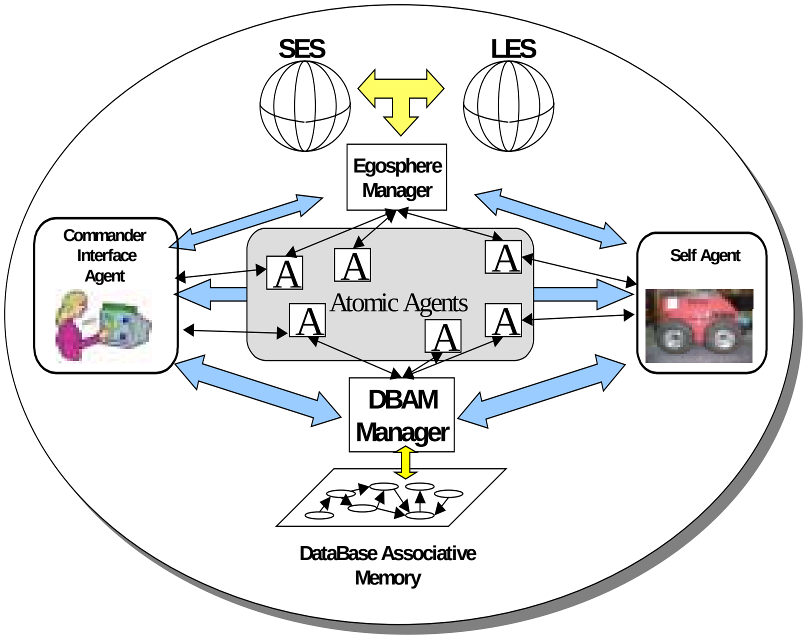
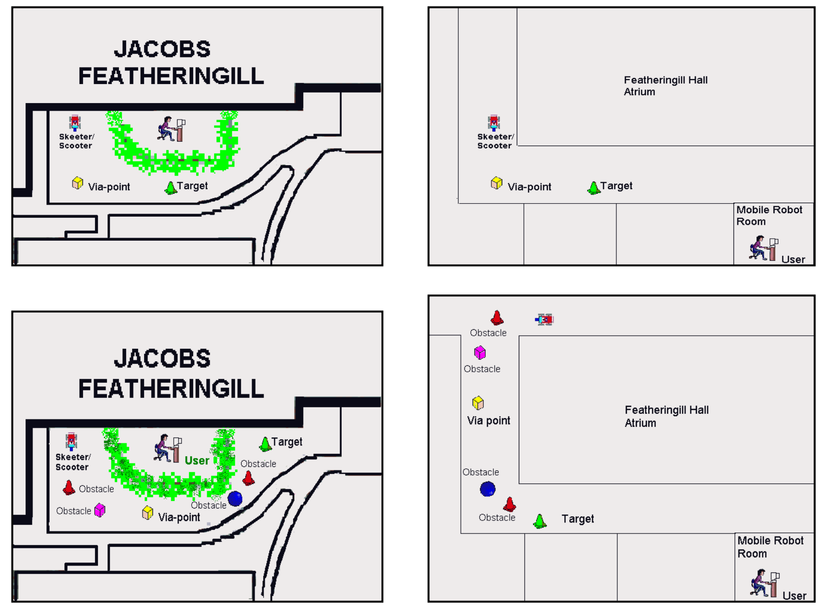


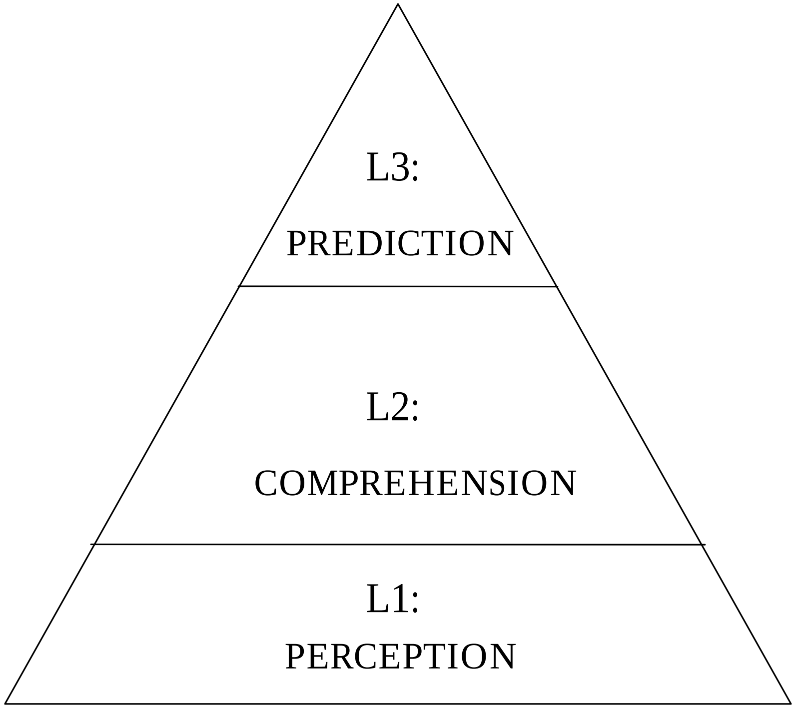
Scenario 1:

- Control
  - Tele-operation with original user interface
- Environment
  - Featheringill Hall patio
  - 3^{rd} floor Featheringhill Hall
- Robots:
  - Scooter (static SES)
  - Skeeter (dynamic SES)



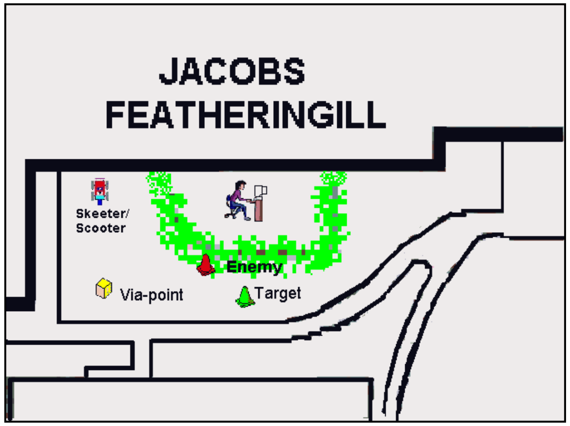
Scenario 2: Situational Awareness

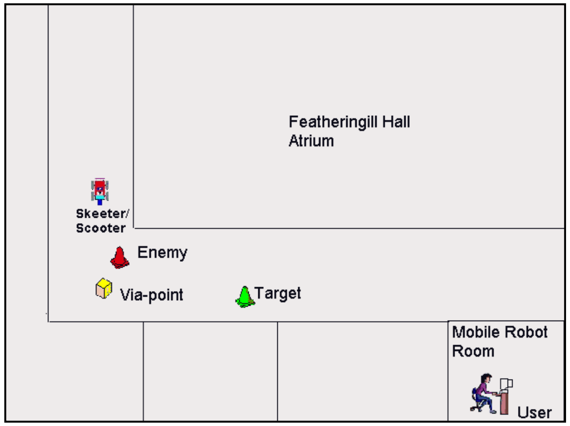
- Situational awareness is the knowledge of what is going on around the human operator or the robot.
- Three levels
  - perception
  - comprehension
  - prediction
- The SES increases SA from level 1, perception to level 2, comprehension



Scenario 2: Situational Awareness

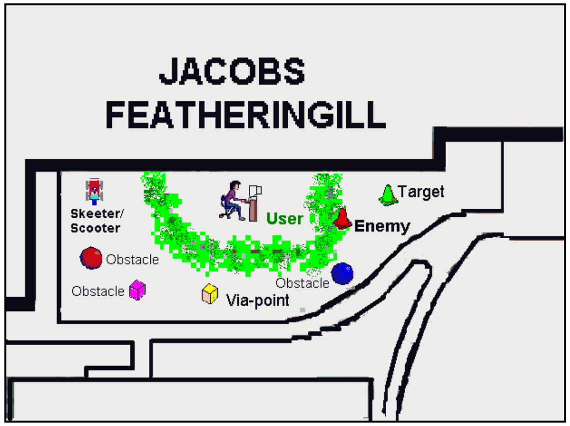
- Control
  - Command the robot to follow a path
- Environment
  - Featheringill Hall patio
  - 3rd floor Featheringill Hall
- Robots:
  - Scooter (static SES)
  - Skeeter (dynamic SES)

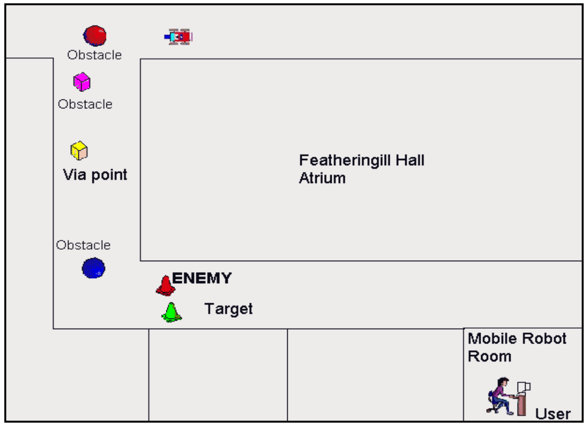




Scenario 3:

- Control
  - Tele-operation with original user interface
- Environment
  - Featheringill Hall patio
  - 3rd floor Featheringill Hall
- Robots:
  - Scooter (static SES)
  - Skeeter (dynamic SES)





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Research Proposal: Schedule Milestones

DELIVERABLE	DATE
SES Graphic	April 30, 2002
SES Agent	May 15, 2002
GUI Manager	June 30, 2002
Final Experimental Design	July 15, 2002
Data Collection	September 15, 2002
Data Analysis	October 30, 2002
Dissertation to Committee	November 15, 2002