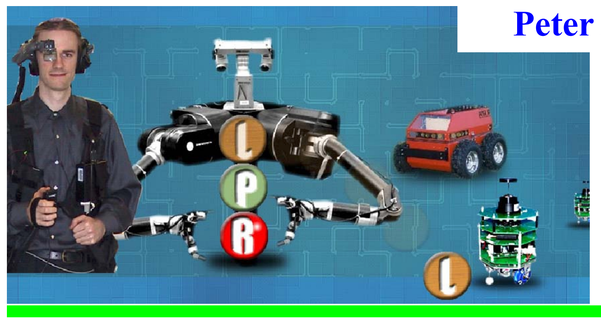
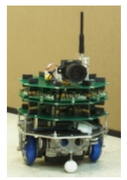
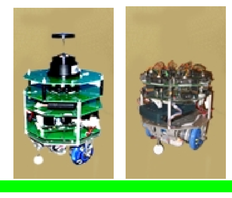
Human-Robot Interaction Through a Distributed Virtual Environment

Andrew H. Fagg, Shichao Ou, T. Reed Hedges, Mathew Brewer, Michael Piantedosi
Peter Amstutz, Allen Hanson, Zhigang Zhu, Roderic Grupen, Edward Riseman

Laboratory for Perceptual Robotics
Wearable Computing Group
University of Massachusetts, Amherst
Department of Computer Science
www-robotics.cs.umass.edu







User Interfaces for Large, Mobile Networks of Sensors and Robots

- Effectively communicate important state information to a user while filtering irrelevant data
- Allow the user to control the resources from a variety of levels
- User involvement in the training and in the shaping of new control policies
- Provide this interaction to users that are located in the field

A Prototype Interface

Focus: search-and-rescue and reconnaissance domains

- Decouple direct connection between user visualization and the data collection process
- Allow user to explore the spatial relationships of remotely-captured data
- Address constraints imposed by network bandwidth and environmental modelling limitations

Architecture Overview

The user is presented with two visual interfaces:

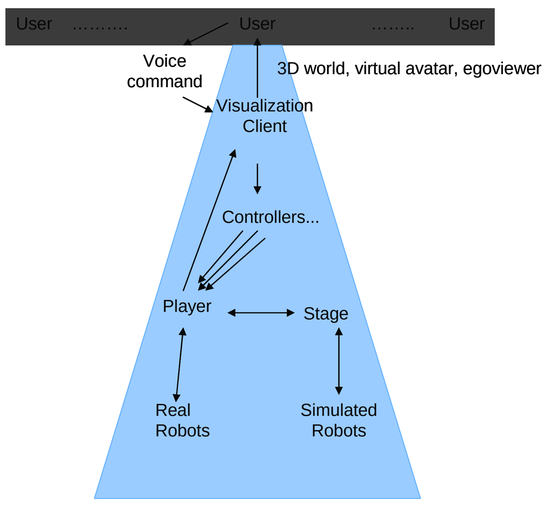
- A 3D virtual reality model of the environment being explored/monitored. The environment representation is distributed across the local network using the general framework provided by the Virtual Object System (VOS)
- High-resolution, panoramic images that have been captured from the environment

The user commands robot/sensor behavior through several interfaces:

- Keyboard/mouse action
- Voice commands (IBM ViaVoice)
- "Gestural" movements within the virtual environment

Robot control is accomplished with a battery of controllers:

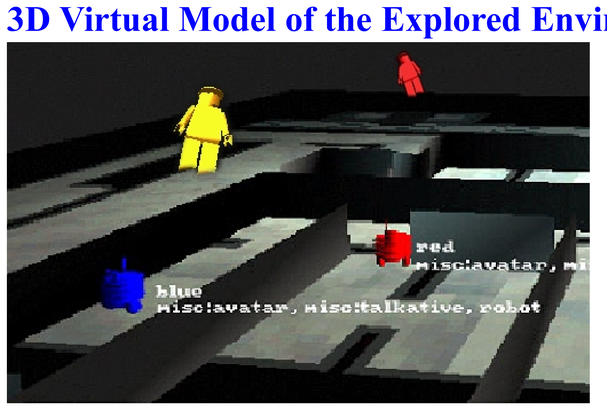
- Robot communication and control through the USC Player/Stage system
- Controllers provide a range of functionality from a low-level "safe-drive"mode to mid-level movement primitives (move to a specific location; capture images)
- Supports both real and simulated robots/environments



Target User Interface Platforms

We employ both desktop and wearable computing systems. The prototype wearable system is based on a Xybernaut MA IV, and is equipped with a full VGA heads-up-display, one-handed chording keyboard, and a three-axis gyroscopic head tracking device (Intersense, Inc.). The head tracking device allows the user to employ head orienting movements to change display perspective.

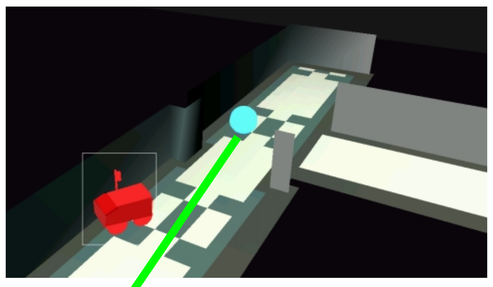
3D Virtual Model of the Explored Environment



- Presents a coarse representation of the operating environment in order to facilitate the user's understanding of the spatial relationships between the environmental landmarks and the deployed robots and sensors
- User's perspective is independent of the robots/sensors, but instead is determined through head movements and keyboard input
- As images are collected by the robots, they are represented as icons within the 3D model at the location corresponding to the camera's viewpoint at the time the image was taken
- Multiple users may share the same environment
- Gesturing support through personal avatar position (e.g., "robot come here")

Panoramic Image Presentation

- Allows user to view detailed imagery from specific viewpoints
- Head movements index viewable portion of the image
- Captured from robot-mounted panoramic camera or generated from multiple images through a mosaicing process
- Future: incremental update of panoramic images and automatic augmentation of images (e.g., highlighting movement)



De-warped Panoramic Image

Mosaiced Image derived from images taken from many (virtual) camera orientations

User Interaction with Dynamically- Formed Teams of Robots

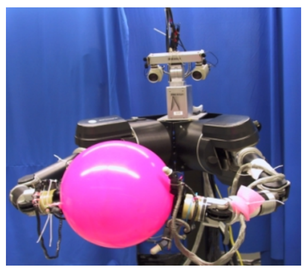
- We are moving away from explicit user interaction with specific resources. Instead, we wish to specify high-level goals (e.g., "gather sensory information about *this* area", "map *this* region of space", or "patrol *this* area")
- System automatically assigns a set of resources to accomplish different subgoals, taking into account resource availability (including locality) and the priority of the request
- User interacts with controller responsible for coordinating the efforts of the set of resources

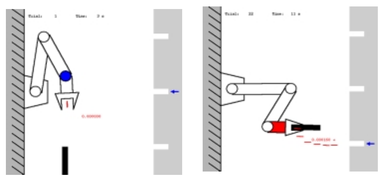
Multi-User Collaboration

- Share workspace between multiple users through the 3D virtual environment
- Collaborative control between desktop and wearable users to solve complex tasks
- Shared points-of-views between field users

Extensions to Humanoid Collaboration, Control and Training

- Human direction and monitoring of many robots involved in distributed repair tasks
- Remote humans as tutors of motor skill: fine control to high-level task learning
- Shoulder-to-shoulder interaction: cooperative task execution; robots/sensors providing additional viewpoints during task performance





Graded Autonomy in Robot Control and Training

(work of Michael Rosenstein)

- Range from teleoperation control to full autonomy
- Human control actions serve dual role as training information
- Future state prediction and display to support human monitoring of autonomous behavior

Future Work

- Event-based, multi-modal (visual and auditory) reporting of state information by the robots (e.g., indicating that a task is complete or that help is required)
- Projection of live data into the virtual environment (e.g., position and identity of tracked subjects)
- Stereo presentation of panoramic imagery
- Presentation of live video imagery within the 3D environment
- Automated mapping and 3D model construction

Sponsors

NSF Research Infrastructure	Sensorimotor Development in Humans and Machines, R. A. Grupen, A. G. Barto, P. R. Cohen, N. E. Berthier, R. K. Clifton, and C. R. Beal
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NASA Graduate Student Researchers Program	Task and Scale Appropriate Closed-Loop Interaction in the Force Domain, Graduate Fellowship to R. Platt
DARPA, MARS	A Software Control Framework for Learning Coordinated, Multi-Robot Strategies in Open Environments, R. A. Grupen
DARPA, MARS	Instructing Robotic Assistants to Acquire Autonomous Behavior, R. A. Grupen, A. H. Fagg, S. Mahadevan
DARPA, SDR	Software, Programming, and Run-Time Coordination for Distributed Robotics, R. A. Grupen