

# Big Signal: Information Interaction for Public Telerobotic Exploration

Peter Coppin\*, Alexi Morrissey\*, Michael Wagner\*, Matthew Vincent\*\*, Geb Thomas

\* The Big Signal Initiative  
The Robotics Institute  
Carnegie Mellon University, Pittsburgh, PA  
15213  
<http://www.bigsignal.net/>

The GROK Lab  
\*\* Department of Industrial Engineering  
University of Iowa, Iowa City, IA 52242  
<http://grok.ecn.uiowa.edu/>

## Abstract

Obstacles must be overcome in order to make viable public distribution of interactive remote experiences via the Internet. High latency and the fact that there are many more users than robots make traditional forms of telerobotics difficult. The Big Signal project seeks to overcome these obstacles using information interaction tightly coupled to a live autonomous rover mission.

*Information interaction allows users to engage in a rich exploratory experience without affecting the robotics mission. Additionally, information interaction adheres to the Internet standard of client/server models that allow many users to interact with one data set of information. In December 1998, Big Signal deployed a prototype project by providing an educational interface that allowed students and the public to participate in remote telescience.*

## 1 Introduction

*Factors of Success for the Internet = Obstacles for Internet Telerobotic Exploration.*

Interactive television, video telephones and the like were the subject of science fiction stories and research labs for years until the low data requirements and decentralized client/server configurations of the Internet converged with suitable modem speeds that could accommodate primarily text based information distribution. Soon image compression techniques allowed digital images to be transferred within a

reasonable amount of time. Now virtual communities and computer gaming allow a decentralized public to interact in virtual space using standardized Internet technologies.

These attributes, which are prime components of success for the transfer of Internet data packets, are the coffin nail for a remote user attempting to engage in a real-time telerobotics scenario.

### 1.1 Problem: Communication Bottlenecks

Controlling an electromechanism in the real world in real time requires monitoring a situation remotely through sensors, sending control commands to the electromechanism, and finally observing the result in enough time to direct the physical machine to its goal.

In the case of the Internet direct telerobotic closed loop control is difficult, because many users participate over low bandwidth connections such as modems. An Internet based remote experience must be structured in such a way that time lags do not affect an exploratory experience.

### 1.2 Problem: Many People, Few Rovers

The second problem is a problem that is not inherent to *Internet* telerobotics, but to *public* telerobotics in general. As a public event, there are usually many more people than there are robots. Several public robotic experiences have attempted to resolve this situation in several ways.

#### 1.2.1 Traditional Approach: One Operator, One Robot

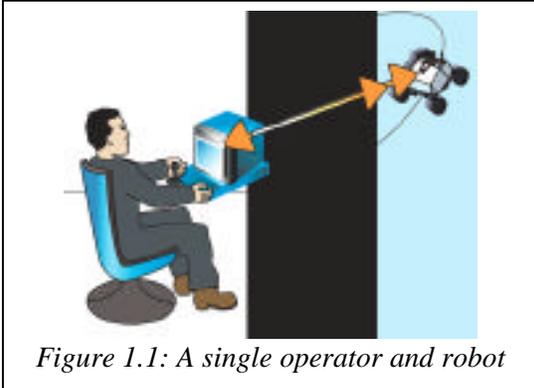


Figure 1.1: A single operator and robot

A traditional approach to telerobotic experience is the one operator, one robot paradigm (see figure 1.1). Though suitable for personal robotic experiences, this is impractical for public experiences where other users must wait in line in order to gain the precious and rarified experience due to its singular nature.

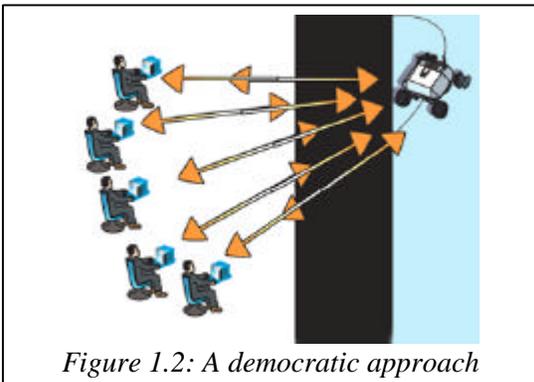


Figure 1.2: A democratic approach

### 1.2.2 Democratic Approach: Voting

A second paradigm used for public telerobotic experiences is a “democratic” voting scenario (see figure 1.2). In this situation, users vote on the direction that a robot may travel or look. An example of this project was part of the public outreach effort for NASA/CMU’s Atacama Desert Trek. [1-3]

In this project, CMU worked with Pittsburgh’s Carnegie Science Center to produce a public interface for the Trek. Live Panoramic imagery was projected onto a hemispherical screen that surrounded a theater equipped with buttons at each seat in the theater. By pushing buttons on these

seats, users were able to vote on the next direction that Nomad would travel. Other buttons controlled the pan/tilt direction of the panoramic image that was projected onto the screen.

Though thrilling to see full color immersive imagery from 5000 miles away updating in real time, this voting scenario required the collective collaboration of a large group of people, resulting in the neglect

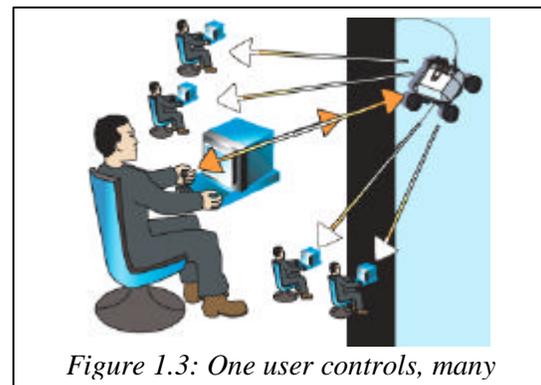


Figure 1.3: One user controls, many

of individual urges in the audience.

### 1.2.3 Hybrid Approach: One User Controls, Others Watch

Another approach to public remote experiences is a one operator / many viewers approach (see figure 1.3).

For example in a project called Rover TV. This venture was an "interactive" television show that allowed viewers to actively explore a remote environment by giving TV watchers control of a the Nomad Rover that was deployed in the Atacama desert of Northern Chile 5000 miles away. Viewers observed live imagery from the Rover and gained control by dialing a number with their touch-tone telephones. Users controlled both camera movements and steering of the rover.

## **2 Solutions Using Autonomous Rover Systems and Information Interaction**

### **2.1 Solution: Eliminate Communication Bottlenecks through Autonomy Systems**

Time lag is not a new issue for telerobotics. Space relevant rover technology has focused on the time lag issue for years because of the amount of time it takes for signals to get from the Earth to off world locations and back again. Space rovers contain autonomy systems to keep them running between information bursts from Earth bound controllers. Some of these systems focus on autonomous navigation and science. One such project that explores the creation of autonomous navigation and science systems is the NASA/CMU Robotic Search for Antarctic Meteorites.[4-6] This project seeks to develop robotic technology that allows the autonomous discovery and classification of rocks and meteorites on Antarctic ice fields. This technology will enable a robot to deploy in an ice field, search this field to some level of precision, spot a potential target, autonomously navigate to it, and classify it as a type of rock or meteorite. Multiple sensor modalities are required to classify a meteorite more effectively than a human scientist, but the robot has limited energy available. Therefore, to efficiently search an area without wasting time or energy requires science autonomy – a capability that does not just safely guide a robot to a waypoint, but actually creates mission plans from higher-level goals.

To further this research, the project sent an expedition team and the robot Nomad to Patriot Hills, Antarctica in October 1998. During this expedition, the polar navigation, ice traversal and meteorite / rock classification capabilities of Nomad were tested. Data from a wide number of sources were sent back to CMU:

- High-resolution images of rock / meteorite targets
- Panoramic images
- Spectrometer results

- GPS information
- Telemetry from Nomad's numerous pose, weather, and other sensors

### **2.2 Solution: Information Interaction**

These many types of information had to integrate into one seamless experience by Big Signal. The limited bandwidth from Antarctica to CMU and bad weather in Antarctica made communications and infrequent; however, each new transmission augmented the data set at CMU's server. These data were processed into a form that could easily be integrated into and publicly accessed in the Big Signal web site. This transformed robotic activity from a one rover / one user model to a client/server type system, optimized for the Internet. The public would now be able to access the wealth of information rather than the robot itself: a model we call information interaction.

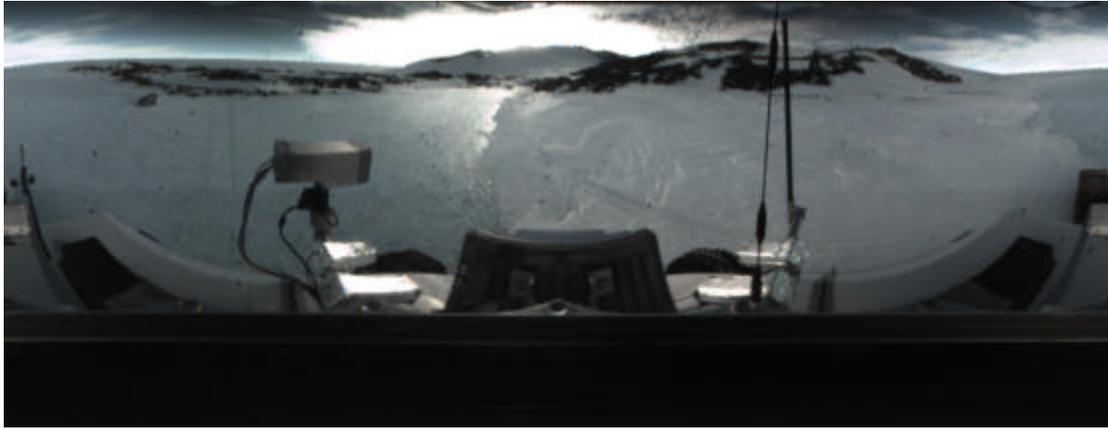
An archive of data on a stateside server continuously downloading from a remote rover provided the perfect framework for a demonstration of public information access to a telerobotic mission.

### **3 Pilot Project: An Educationally Relevant Remote Science Interface**

In the fall of 1998, the Big Signal team created a prototype project consisting of an interactive web site that linked selected pilot classrooms with the 1998 RAMS mission. This project provided a perfect platform upon which to test and demonstrate the use of information interaction for remote science in a public setting.

Classroom teachers, interface designers, web designers, illustrators, videographers and robotics researchers worked together to both create content and adapt robot telemetry to web formats that students and teachers could access from the classroom. Pilot classrooms focused on the areas of physics, remote geology, and technology education.

Students using Big Signal encountered several interface features that engaged them



*Figure 3.1: Panoramic images provided a tangible link to the remote environment.*

in the active experience of remote exploration.

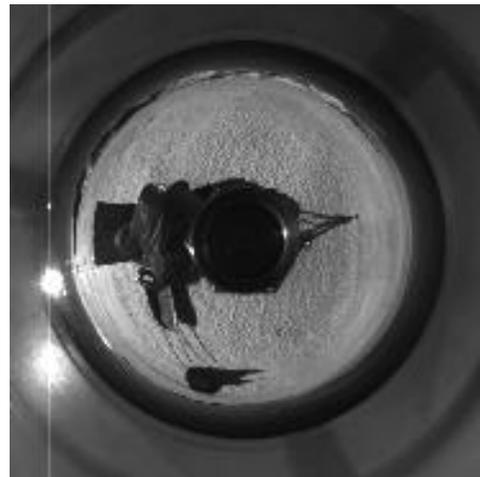
### **3.1 Remote Sensing**

The most visible connection to Antarctica was a continuously updating panoramic image taken by a camera onboard the rover and sent with other robot data via the communications link to the project web server in Pittsburgh. This updating image allowed students to gain a tangible view of the most recent condition of the environment in Antarctica (see figure 3.1)

Students viewed these panoramic images over the web using Apple's QuickTime VR Plug-ins. This downloadable cross-platform standard virtual reality technology plug-in was the perfect counterpart for Nomad's unique imaging system specifically designed to acquire complete 360-degree images, as shown in figure 3.2.

Custom software converted the panospheric images acquired by Nomad into mercator projection (panoramic) images required for input into the web friendly and high performance QuickTimeVR Movie conversion program. Use of this VR technology created an immersive experience for the students while using minimal computational resources to support the user controlled photorealistic movie capability. Figure 3.3 illustrates the method by which the raw panospheric image converts to a QuickTime VR format.

The ultimate goal of creatively applying virtual reality technology to quickly and reliably exchange information between the robot and the students was the ultimate goal of this aspect of the user interface. The panospheric to QuickTime VR interface design approach was a significant success factor in achieving this goal.



*Figure 3.2: Unaltered 360-degree panoramic photograph.*

### **3.2 Data Reduction**

In addition to direct links to sensory information, Big Signal also reduced raw data sent from Antarctic. Therefore, technical facts could be presented in a manner easily understood by students and the public. There were three main aspects of Big Signal that used reduced data.

# Panospheric to QTVR Conversion

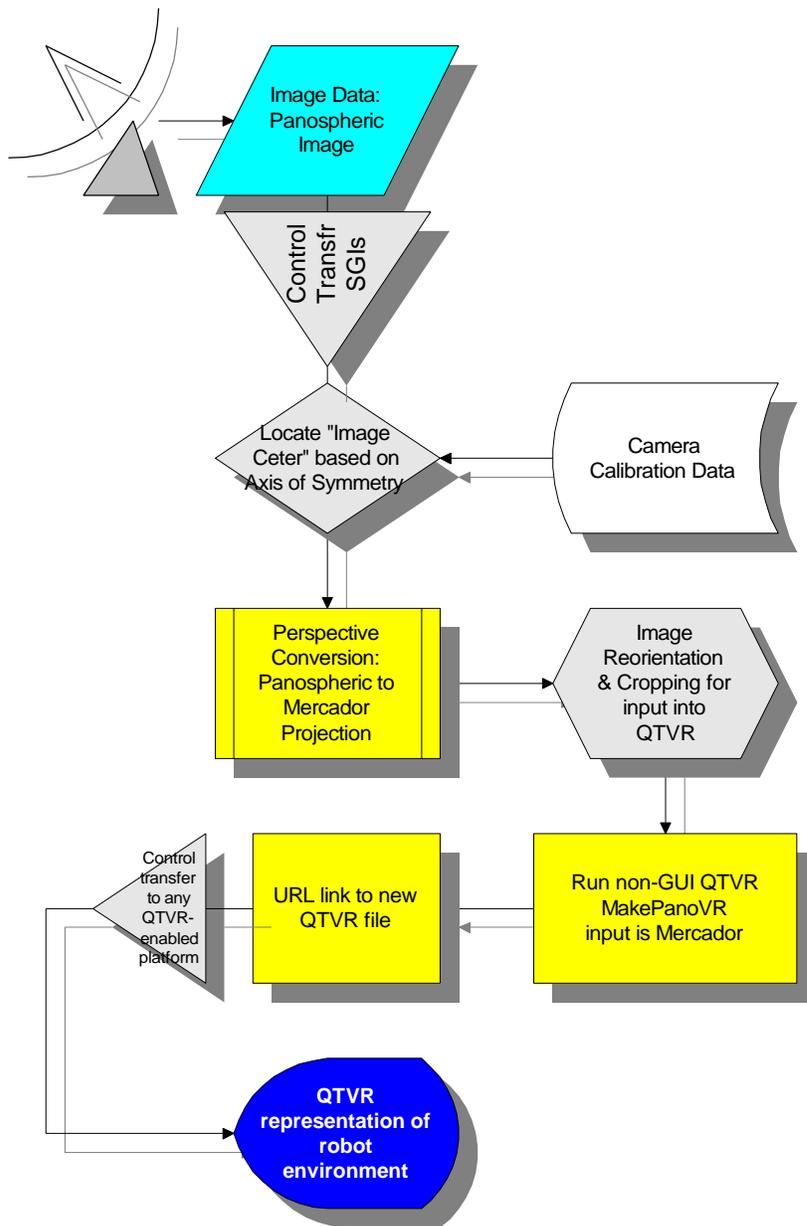


Figure 3.3: Panospheric to QuickTime VR conversion methodology.

### 3.2.1 An “I Robot” Interface

A scrolling “I Robot” text bar automatically presented late breaking events coming from the rover. By clicking on words in this scrolling text bar, students were able to link to more detailed background information that allowed them to understand late breaking events.

The text displayed in the “I Robot” scrolling text bar was comprised of processed network messages inside the robot. These messages were recorded as telemetry and sent back to Pittsburgh. Software at CMU automatically analyzed the telemetry. Interesting combinations of network messages converted into English sentences, structured in first person perspective to sound as if the robot were personally informing the web user.

Although the text generation process was not elaborate, an “I Robot” style of interaction is capable of enhancing the experience of a telerobotic user. First, the robot presented itself in a personal, human manner, making it more engaging to novice users. Second, it is an effective way to communicate mission updates, because it posts data immediately to the center of the user’s screen in an easy to understand format.

### 3.2.2 Interactive Map

“I Robot” data mining provided raw materials for other interface elements. Robot position information was correlated with science finds and images, then plotted onto a continuously updating interactive map that acted as a visual, clickable interface to the progress of the mission.

Icons on this map represented current and past positions of the rover. Clicking map icons activated datalogs, science data, and scientist reports from previous days in the form of daily report pages.

Map visualization was created with Virtual Reality Markup Language (VRML); a cross-platform dynamic three-dimensional standard that was interfaced with rover database protocols. Remote users explored

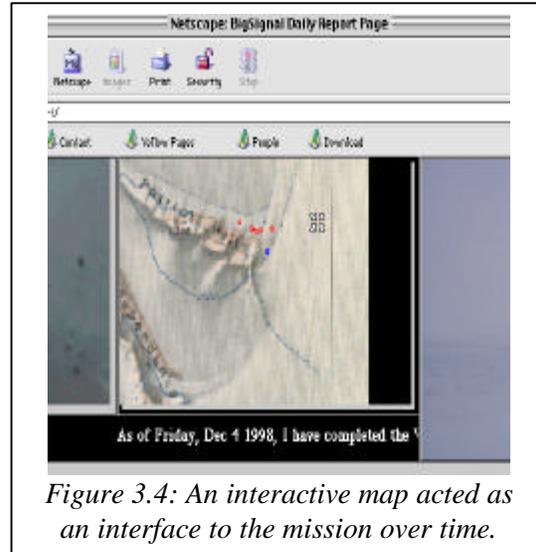


Figure 3.4: An interactive map acted as an interface to the mission over time.

interactively the dynamically updated virtual landscape. The modeling language enables the creation of a 3D scene in which the user observes the entire expedition area (see figure 3.4). The user can select icons that present further scientific information or activate the QuickTime VR window with a VR scene from that exact robot position on the map. This holistic view of the exploration allowed a vantage point by which users can see the total progress of the exploration as well as have a sense of orientation to local landmarks, before entering the QuickTime VR robot environment. User disorientation was prevented by restricting map manipulation orientation angles, while still allowing “zoom in” and “zoom out” capabilities. Figure 3.5 diagrams the method used in converting incoming GPS data into VRML map icons.

### 3.2.3 Daily Report

The daily report functioned as both a repository for robot data types and as a source for news about the team and the exploits of the robot from a human point of view. Research external to the robot was also posted in the Daily Report. The Daily Report was designed to interface to users accessing Big Signal from the twelve pilot libraries in Allegheny County, Pennsylvania. This aspect of the page also proved useful to researchers affiliated with

# GPS data conversion to VRML

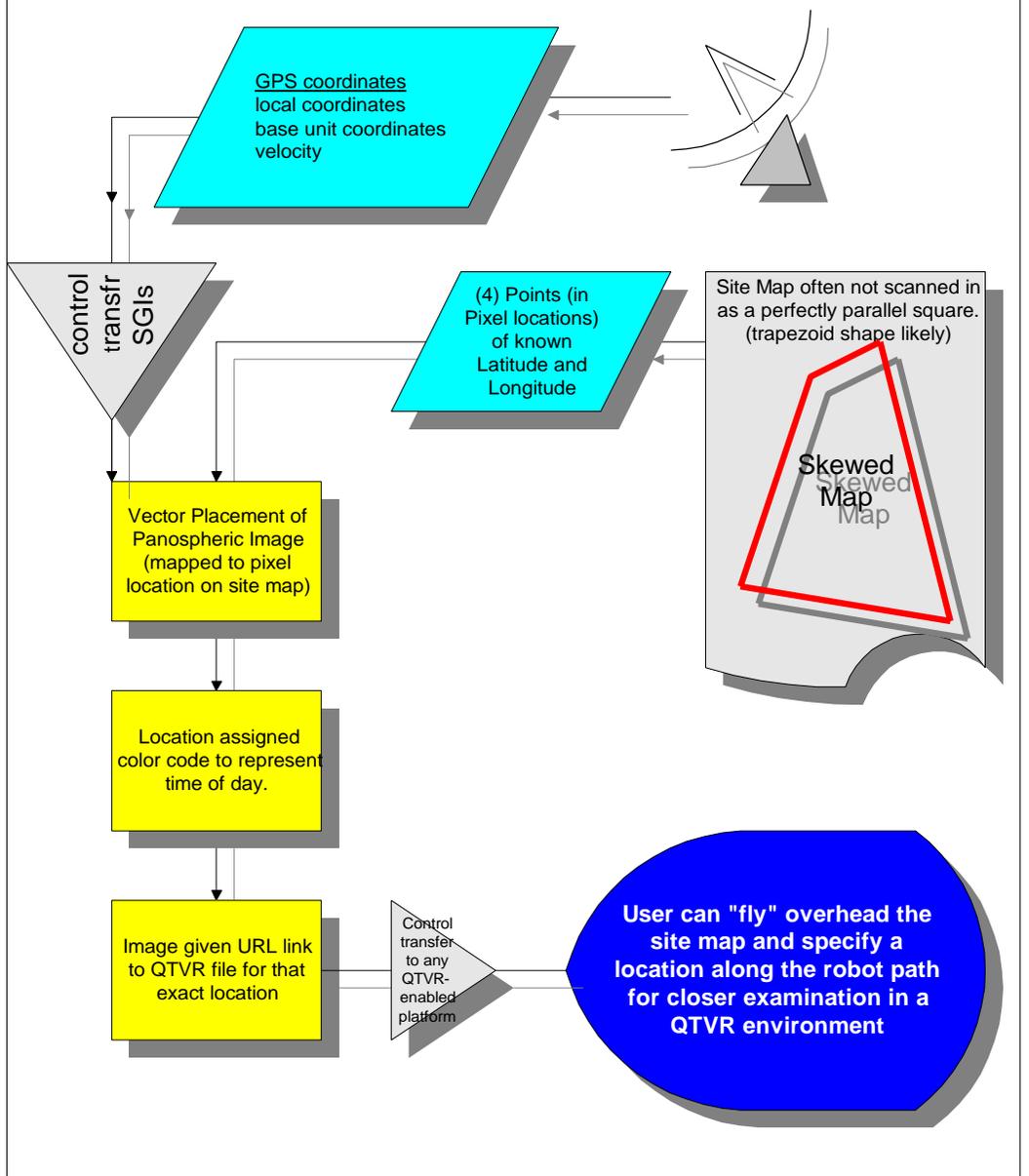


Figure 3.5: GPS data conversion to VRML

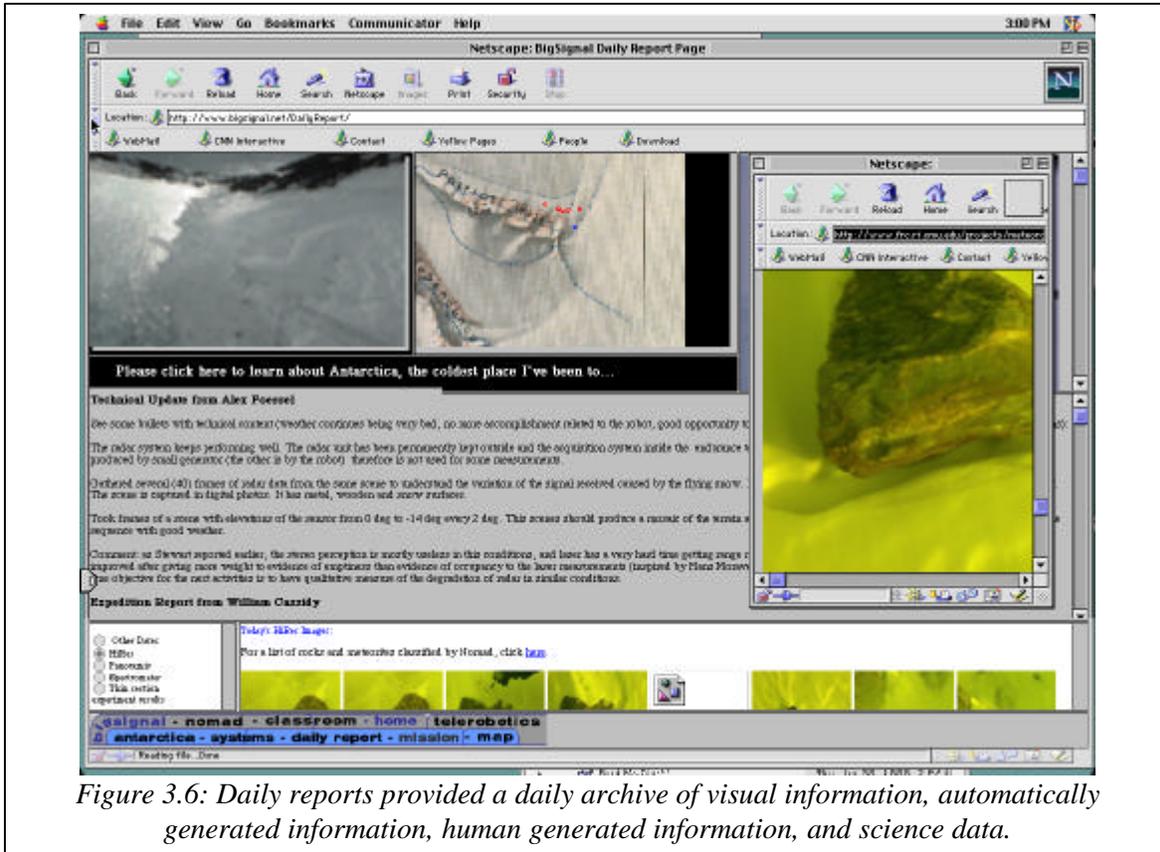


Figure 3.6: Daily reports provided a daily archive of visual information, automatically generated information, human generated information, and science data.

the project who were not participating in the field test. The Daily Report section was a combination of data automation and information created manually by the Antarctic expedition team (see figure 3.6).

Users could select from various dates from the mission to gain an understanding of the field operations through basic research notes and journal entries posted by the expedition team and automatic data.

### 3.3 Novice User Information and Visualization

As a public interface for a telerobotics mission, users could not be expected to have prior knowledge of telerobotics, remote science, rover operations, or science operations. The Big Signal site contained background information that focused on telerobotics concepts such as autonomy and

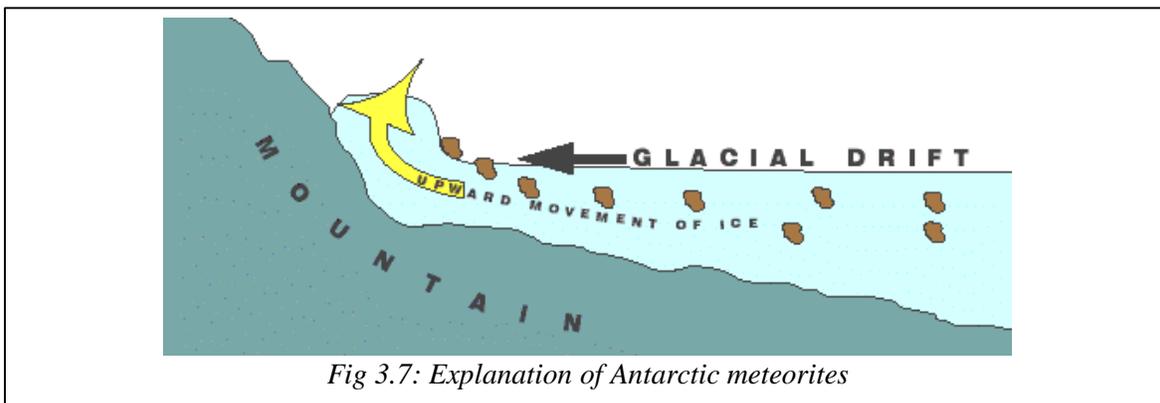
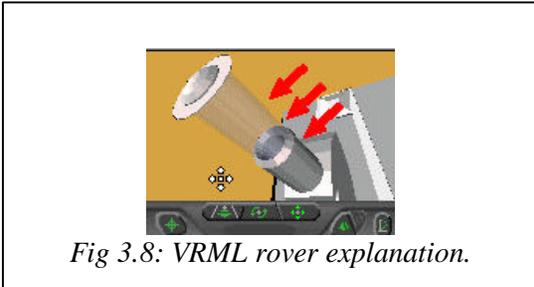


Fig 3.7: Explanation of Antarctic meteorites

remote science, mission information, and information about Antarctica.

A variety of information types such as text explanation, video clips, and VRML 3D visualization were used for explanations (see figures 3.7 and 3.8).

The “I Robot” scrolling text bar was also linked to explanations. Thus as a viewer was presented with new information due to late breaking events, clicking the text bar would activate pre-written information about a chosen topic.



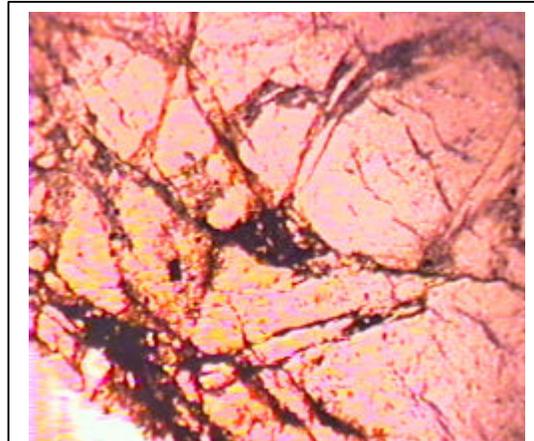
*Fig 3.8: VRML rover explanation.*

### 3.4 Classroom Activities

The three pilot classrooms were chosen based on the particular systems and mission plan of the Nomad robot. Professional educators met with the Big Signal team and the researchers who built the robot to design classroom activities based on existing high school standards set by the state of Pennsylvania for Science and Technology. This approach led to a sustainable relationship with the teachers so that the Big Signal Interface could be used as a teaching tool over a period of three weeks.

#### 3.4.1 Earth Science and Astronomy

Big Signal allowed for telescience by giving students access to data sets from the Antarctic that were relevant to their course of study. For example, figure 3.9 shows a thin section of a terrestrial rock that was cut in situ by planetary scientist Pascal Lee from the NASA Ames Research Center and sent to the Daily Report section of the interface via satellite.



*Figure 3.9: Thin section of a rock, used in Big Signal (Courtesy NASA Ames Research Center)*



*Figure 3.10: Students investigate robotic chassis designs*



*Figure 3.11: High school physics experiment*

#### 3.4.2 Technology Education

Technology education students investigated Nomad’s mechanical and

electromechanical system. Pre recorded video of the robot along with diagrams and animations available on the web interface showed how various functions of the robot worked. Figure 3.10 shows a student team as they analyze their preliminary design for an expanding chassis.

### **3.4.3 Physics**

Physics students in figure 3.11 measure the footprint of a four-wheeled vehicle similar to the robot for their pressure VS area assignment. Physics students used a combination of live data from the field as well as prerecorded web archives off Big Signal to fulfill their work.

## **4 Continuing Research**

Several proposed research thrusts in Big Signal and at the Robotics Institute of Carnegie Mellon University will greatly augment the capabilities of information interaction. Big Signal seeks to apply these technologies to future educational and public outreach experiences based on information interaction.

### **4.1 Information Request Servicing Systems**

Public participants in the Robotic Search for Antarctic Meteorites were unable to add information to the existing data set. To participate, a user must be able to request information that is currently not in the data set. However, as observed above, one rover cannot simultaneously handle requests from many users. Therefore, software must be developed to handle, intelligently and autonomously, requests to fill information into the existing data set. This software would analyze the information requests of many users to create a mission plan that most efficiently services all requests. This mission planner would seek to create a plan that is least costly with respect to aspects such as time or energy. Techniques developed for the science autonomy system of Nomad could be used to evaluate the energy and time costs of a particular information request.

Additionally, the software could take advantage of any requests that could be serviced with a single action (for instance, requests for medium resolution images of two rocks could be handled by one aerial image).

This type of software would seamlessly fill gaps in the existing data set, allowing smooth information interaction. Unlike current mission planning systems, the very goal of the robot would be to facilitate information interaction.

### **4.2 Advanced Virtual Workspaces**

A proven technology born from early investigations into the science of human-machine systems is telepresence. Until recently, telepresence has been regarded as the use of low-bandwidth, low-resolution video as a forum to create 2-D imagery for the remote control of robots in dangerous terrain. Recently, in the Mars Pathfinder mission, telepresence evolved, resulting in a full 3-D reconstruction of the landing site. This proved that a full remote experience is a captivating and indispensable mission component. The resulting 3-D maps were used by the rover drivers and mission scientists, as well as enjoyed by the general public on the World Wide Web. Virtual reality technologies were advanced to the forefront of telepresence frontiers. While these technologies are currently highly successful, they must now be re-thought and transformed in order to realize their full potential.

Carnegie Mellon, The Iowa GROK Lab, and NASA Ames Research Center seek to address some of the fundamental research problems in 3-D virtual reality discovered during Mars Pathfinder and testing of Chernobyl's Pioneer. In addition, they propose to transform the existing technologies to the point where construction of large scale, integrated photo-realistic models is possible. These models will incorporate orbital, descent, and ground-based acquisitions into a model of the virtual

workspace that exploits the full range and redundancy of information currently available to the science and operations teams, but in a novel form that is both compact and accessible.

The use of three-dimensional visualization tools creates new opportunities for public outreach, education, and public telerobotics in a way that was not previously possible. Such representations of remote sites allow the public to experience a mission in a user-friendly way through the active visualization of mission data within the public realm of the World Wide Web.

#### **4.3 Advanced “I Robot” Interface with User Context**

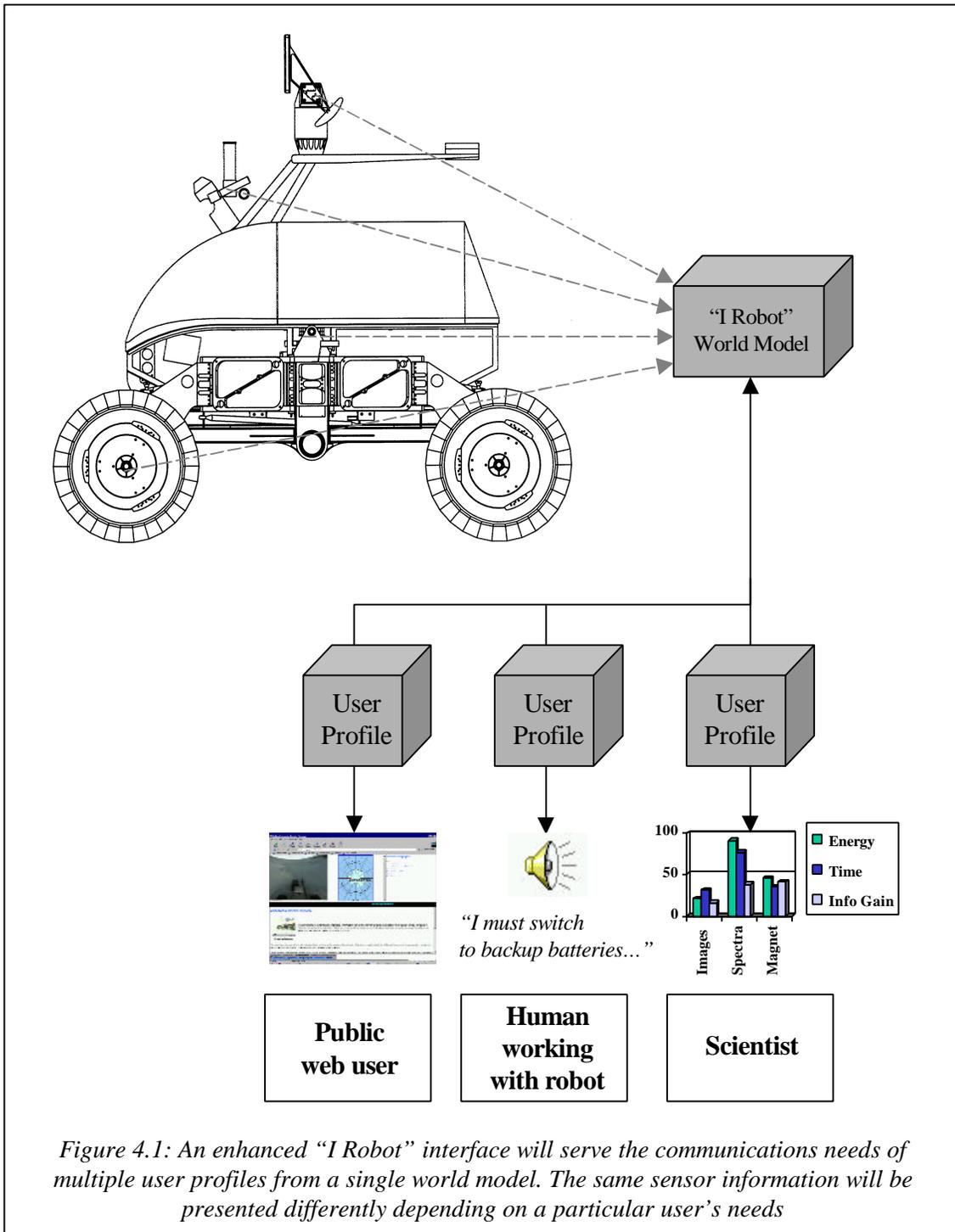
Human communication depends on an understanding of context. Human speakers choose appropriate communicative modes based on the situation and on the distinct qualities of the audience. Effective speakers implicitly take into account the intelligence, motivations, knowledge, interests and experience of their audience. This awareness allows the speaker to create sentences that are quickly understandable and contain high-level meaning.

Human/machine interfaces typically transmit large quantities of raw, numerical data because computers excel at very fast and accurate measurements. Users may become overwhelmed by large amounts of data, or may be distracted by many competing sources of information. Although the active field of human-computer interaction (HCI) has developed data presentation techniques to ease the use of human/machine interfaces, they do not use context to communicate. A “one size fits all” interface that attempts to meet the lowest

common denominator of user will not be sufficient for complex future human/machine cooperation. An interface centered on the context of a human user rather than one based on robotic technology must be created in order to maximize the benefits of human-computer interaction.

Researchers at Carnegie Mellon University seek to develop “I Robot” into human/robot interface model that creates self-motivated robotic agents designed to inform a wide-ranging user base. It will proactively communicate high-level inferences and explanations tailored to context-specific human goals and interests. The types of users that contact the robot may require different information in different formats, so explanations will be presented in formats appropriate to the needs of particular users (see figure 4.1).

This objective encapsulates two research goals. The first goal addresses the need for relevant and naturally understandable explanations. Determining relevance and understandability requires that we characterize the goals of people that will use this type of interface. This research will therefore seek to define three main features of an “I Robot” interface user: motivations, areas of interest, and communication format requirements. The second research goal will be to develop an information processing architecture that facilitates the kind of human/robot partnerships required to enable the creation and delivery of robotic explanations. This interface architecture must be modular to support many types of data sources, such as sensors, as well as information destinations, such as graphical displays.



## Acknowledgements

Additional contributors to this paper and supporters of the Big Signal Initiative include: the Grable Foundation, the Electronic Information Network, the Frick Fund of the Buhl Foundation, the Howard Heinz Endowment, Bob Namestka, Dawn Lambeth, Scott Thayer, the Robotic Search for Antarctic Meteorites, and the Field Robotics Center at Carnegie Mellon University.

## References

- [1] Shillcutt, Kimberly and William Whittaker, "Modular Optimization for Robotic Explorers," Integrated Planning for Autonomous Agent Architectures, AAAI Fall Symposium, Orlando, FL, October 23-25, 1998.
- [2] "The Atacama Desert Trek - Outcomes," with D. Bapna, M. Maimone, J. Murphy, E. Rollins and D. Wettergreen. Submitted to the 1998 IEEE International Conference on Robotics and Automation.
- [3] "Lessons from Nomad's Trek in the Atacama Desert," Dimitrios Apostolopoulos, Red Whittaker. 1999 International Topical Meeting on Robotics and Remote Systems for the Nuclear Industry, Pittsburgh, PA, Apr 1999 (accepted)
- [4] "Pattern Search Planning and Testing for the Robotic Antarctic Meteorite Search," Kimberly Shillcutt, Dimitrios Apostolopoulos, Red Whittaker 1999 International Topical Meeting on Robotics and Remote Systems for the Nuclear Industry, Pittsburgh, PA, April 1999 (accepted)
- [5] "Sensing and Data Classification for Robotic Meteorite Search," Liam Pedersen, Dimitrios Apostolopoulos, et al. Proceedings of the XIII SPIE Conference on Mobile Robots, Boston, MA, November 1998
- [6] "Field Validation of Nomad's Robotic Locomotion," Ben Shamah, Dimitrios Apostolopoulos, Eric Rollins, Red Whittaker Proceedings of the XIII SPIE Conference on Mobile Robots, Boston, MA, November 1998