IMMERSIVE ENVIRONMENT TECHNOLOGIES FOR MARS EXPLORATION J. Wright and F. Hartman, Jet Propulsion Lab, john.r.wright@jpl.nasa.gov, frank.hartman@jpl.nasa.gov

Introduction: JPL's charter includes the unmanned exploration of the Solar System. One of the tools for exploring other planets is the rover as exemplified by Sojourner on the Mars Pathfinder mission. The lightspeed turnaround time between Earth and the outer planets precludes the use of teleoperated rovers so autonomous operations are built in to the current and upcoming generation devices. As the level of autonomy increases, the mode of operations shifts from low-level specification of activities to a higher-level specification of goals. To support this higher-level activity, it is necessary to provide the operator with an effective understanding of the in-situ environment and also the tools needed to specify the higher-level goals. Immersive environments provide the needed sense of presence to achieve this goal.

Use of immersive environments at JPL has two main thrusts that will be discussed in this talk. One is the generation of 3D models of the in-situ environment, in particular the merging of models from different sensors, different modes (orbital, descent, and lander), and even different missions. The other is the use of various tools to visualize the environment within which the rover will be operating to maximize the understanding by the operator. A suite of tools is under development which provide an integrated view into the environment while providing a variety of modes of visualization. This allows the operator to smoothly switch from one mode to another depending on the information and presentation desired.

Terrain Modelling: The creation of 3D models of the in-situ environment begins with imagery collected by orbiting instruments which utilize stereo image processing to generate elevation maps of the terrain. Viking data has produced such elevation maps for the vast majority of Mars that are georeferenced and registered with imagery. This provides a baseline model for the 3D representation of a given operational area. Descent imagery captured by a lander is the next input and this is processed by unique methods developed at JPL to generate elevation and landmark maps of the landing area. The descent images provide lower resolution data over a large area and higher resolution data in the immediate area of the lander. The elevation maps produced from the descent imagery are then registered with the baseline dataset to create a multiresolution, georeferenced image and elevation map set.

The final piece of data is captured by the lander/rover. The stereo imagers on the lander capture the immediate surroundings at very high resolution. However, it is difficult to utilize standard image processing methods to attempt to register the lander images to the baseline model. This is due to the extreme difference in position and pespective that a lander on the surface has relative to an orbiter or other airborne instrument. The lander can image areas under overhanging boulders or other structures that are invisible in the previous datasets. To circumvent this problem, the registration process takes place in 3D utilizing the geometry of the baseline dataset to register with the geometry of the surroundings generated by stereo processing of the lander imagery. This process is well supported by the use of voxels and octrees which provide inherent multiresolution dataset support with relatively low storage requirements.

The generation of 3D models for the lander site is a process described by Ivanov, et al [1]. The process uses image correlation processes to register all the images captured by the lander cameras into a panoramic mosaic. This provides for correction of camera pointing errors. Registering the resulting 3D models to the baseline geometry provides an additional correction computation to make further improvements in pointing data and to register the models to the baseline geocoordinates. For a rover, this process can be iterated as the vehicle travels to new locations and captures stereo imagery of the surroundings. Each patch can be registered to the baseline model and the entire set of data maintained in a cohesive fashion.

Immersive Planning Tools: During Pathfinder, the terrain models built from the IMP imagery extended a few meters out from the lander. If the operators wanted to traverse to a location outside this region, there was no model and no imagery to assist them in planning the sortie. With the multiresolution datasets described above, there will be models with varying resolution extending across the entire planetary surface, or at least multiple kilometers. This will allow the operators to plan traverses to previously unexplored areas with more assurance of traversability and reduced mission risk.

As rovers gain autonomy, the sortie planning process shifts from a low level specification of commands to a higher level specification of goals. These higher level specifications will include such things as traverse to a waypoint and activate instrument at this location. The role of the operators will include more analysis of the in-situ conditions and rover state and less low level control of behavior. The Rover Control Workstation (RCW) under development provides a variety of tools, in an integrated environment, to provide the operator with the greatest understanding of the in-situ environment and rover state possible. Multiple visualization modalities, combined with a robust message passing environment, provide common views into the in-situ environment and planned activities. In addition, collaborative sortie planning operations are supported.

The RCW deployed for the Pathfinder mission was based on two basic visualization tools, the Stereo View and the Flying Camera View as described by Cooper [3]. These two basic modalities are continued in the updated version and combined with a Map View tool to provide the most important visualization functions of the in-situ environment. The Stereo View mode provides the most basic, raw look at the image data returned from the stereo imagers. The imagery is displayed using a stereo monitor with the individual stereo pairs arranged in position relative to the camera pointing when the images were captured. Use of stereo glasses provides the operator with a view of the data in its least processed form. Depth and other stereo cues allow the operator to get a fundamental feel for the environment. The minimal level of processing ensures that no artifacts have been added to the data and that no important features have been hidden.

One problem with the Stereo View tool is that it is very difficult for a human to judge the separation of objects in the foreground and background so as to decide if the rover can fit between two rocks. The Flying Camera tool alleviates this problem by providing a means to examine the in-situ environment from any vantage point. The stereo imagery from the imagers is processed to generate a 3D model of the terrain in the immediate vicinity. This model is stored in a form that can be loaded and visualized with a high level of detail and interactive rendering rates. The camera can then be positioned to view possible routes and constrictions to verify that the rover can indeed traverse the planned route. The Flying Camera tool also supports visualization of a model of the rover that can be positioned anywhere within the environment to verify fit and feasibility.

The Map View tool adds a natural, maplike visualization mode to the suite of tools in the RCW. Consisting primarily of descent imagery, the Map View tool displays the sortie planning area from above at various resolutions depending on the availability of data. It also provides natural access to georeferencing information and to navigation data such as landmark datasets, reference points, and direction. It is easy to lose direction in the Flying Camera tool but the Map View tool displays a compass indicating North when desired. Another indicator points to a specified reference point, such as the lander, to make it easier to navigate samples back to a return vehicle, even when out of sight of the lander. Other features of the Map View tool include specification of hazard or protected regions and contour lines for analysis of slope.

The other main component of the RCW for sortie planning is the Activity Editor which is essentially a text visualization tool for displaying the sequence of commands being produced. All four tools are integrated with a message passing executive which maintains a consistent view of the planned sequence among all the tools. Commands, such as traverse to waypoint, may be specified in any of the tools and the creation or editing of such a command is immediately reflected in the other tools. Additionally, multiple copies of each visualization tool may be launched by the same executive yet running on distributed systems to provide for a collaborative planning environment.

Other tools to be integrated within the RCW include a Telemetry Visualization tool to review the previous period's activities as reported by the rover and a Sortie Rehearsal/Simulation tool to perform dynamic simulations of the planned sorties. Comparison of expected behavior to reported behavior can provide important clues to rover performance.

References:

[1] Wright, J., Hartman, F., and Cooper, B., Immersive Environments for Mission Operations, Beyond Mars Pathfinder, proceedings of SpaceOps ‘98, Tokyo, Japan, June, 1998..

[2] Ivanov, A., Lorre, J., and Maki, J., Image analysis for robotic exploration of Mars, ibid.

[3] Cooper, B., Driving on the Surface of Mars Using the Rover Control Workstation, , proceedings of SpaceOps ‘98, Tokyo, Japan, June, 1998..