**VISUALIZING MARS USING VIRTUAL REALITY: A STATE OF THE ART MAPPING TECHNIQUE USED ON MARS PATHFINDER.** C. Stoker, E. Zbinden, T. Blackmon, and L. Nguyen, NASA Ames Research Center, Moffett Field, CA 94305

**Introduction:** We describe an interactive terrain visualization system which rapidly generates and interactively displays photorealistic three-dimensional (3-D) models produced from stereo images. This product, first demonstrated in Mars Pathfinder [1], is interactive, 3-D, and can be viewed in an immersive display which qualifies it for the name Virtual Reality (VR). The use of this technology on Mars Pathfinder was the first use of VR for geologic analysis. A primary benefit of using VR to display geologic information is that it provides an improved perception of depth and spatial layout of the remote site. The VR aspect of the display allows an operator to move freely in the environment, unconstrained by the physical limitations of the perspective from which the data were acquired. Virtual Reality offers a way to archive and retrieve information in a way that is intuitively obvious. Combining VR models with stereo display systems can give the user a sense of presence at the remote location. The capability, to interactively perform measurements from within the VR model offers unprecedented ease in performing operations that are normally time consuming and difficult using other techniques. Thus, Virtual Reality can be a powerful a cartographic tool.

**3-D Model Production:** For Mars Pathfinder, 3-D models of the Martian surface were rapidly created from stereo images taken by the lander's IMP camera [2] using a computational algorithm called the "Ames Stereo Pipeline". The core component of the Stereo Pipeline is the automatic matching of features in the left and right eye camera images, thus providing the necessary correspondence to compute a 3-D location for the feature. Stereo images are first normalized and edge enhancement is applied. Then they are rectified to remove epipolar and rotational offsets. Next, the features in the left and right images are automatically correlated. A texture based sum of absolute difference algorithm is used and the consistency of each match is validated by doing both a correlation and cross-correlation. The disparity, the difference between the position of the area and the match, is computed for each pixel for which a match is found. Multipass cross-correlation is used to minimize the number of non-matches but some occur due primarily to image borders. Using the known camera pointing geometry and optical characteristics of IMP, the disparity values are used to calculate a set of object points in 3 dimensions which, when connected, form the vertices of a polygonal mesh. For the Pathfinder mission, 3-D models were generated at a resolution of 4x4 (1 vertex for every 4 pixels in both azimuth and elevation directions) and 8x12. Finally, the original image is used as a texture map for the 3-D polygonal mesh.

A significant asset for the Pathfinder operation was the rapid production and display of the models. The time to process a single pair of IMP stereo images into a 3-D model was less than 25 seconds with computations performed on a dual processor Octane (2 195 MHZ RS10000, 256 MB RAM) from Silicon Graphics, Inc. The fist complete stereo panorama sequence taken after deployment of the IMP, known as the `Monster Pan', was comprised of 98 stereo pairs. These data were displayed in virtual reality at mission control within one hour of downlink.

**VR Display Interface:** Pathfinder VR models were displayed with a user interface package called MarsMap to display the 3-D models in VR. MarsMap was designed to be accessed with a standard 2-D mouse and uses pull-down menus to call features. Models can be viewed in stereo using Stereographics CrytalEyes LCD shutter glasses or with a head mounted display for full immersion VR. Several modes of motion control for viewing the model are available. In "Drive mode" a user can move around the model at a constant elevation, most useful for navigating close to the surface. Anchor mode allows the user to select and move with respect to an "anchor" point in the model. The user can zoom (towards or away) from the selected anchor point, as well as rotate (horizontally or vertically) around it. Dome mode allows the user to enter azimuth and elevation coordinates that anchor the viewpoint as if looking from the IMP camera in the specified direction. An overlay can be superimposed over the model to display compass headings and a distance grid.

*Measurement Tools.* Marsmap contains user-operated virtual tools to interactively obtain 3-D positions, distances, and angles. All measurement tools are based upon a 3-D cursor graphically representing orthogonal axes aligned with the Mars local level coordinate frame. The 3-D cursor was designed to follow the 2-D mouse cursor on the screen and intersect the front-most polygon in the VR model to yield its 3-

D position. The position of the 3-D cursor was displayed in a window on the screen. Distances and angles can be measured with values printed as an overlay on the model.

*Map Markers.* MarsMap provides capability to place icons ( 3-D overlays) in the model which can be toggled on/off using a pull-down menu. The map markers were used to display the location and sequence of Sojourner science experiments, to display names and locations of prominent rocks at the site, and to display the traverse path of the rover.

*Sojourner Positions.* Sojourner position and heading information, as determined after each traverse using IMP images, is represented in the VR world by placing a 3-D object model of the rover into the VR model at the appropriate position. The Sojourner position models can be toggled on/off using a pull-down menu.

*Sojourner Images.* Images from the Sojourner rover cameras were integrated into the VR model as 2-D billboards projected from the rover's point-of-view. Using the rover position and heading information from telemetry readings, and the image size, a 2-D projection window is defined in the 3-D model. The Sojourner image is then placed in the model at the projection window, along with an object model of Sojourner located at the correct position and heading.

**Uses Of VR Models On Pathfinder:** The VR model provided the Pathfinder team with a valuable tool for performing mission planning and operations, science analysis, and public outreach. A few examples of its uses are summarized here.

*Mission Operations and Planning.* Early in the mission, the VR model was used to measure the angles of the ramps used for deploying the rover, to help determine whether the rover could be safely deployed. It was used to plan Sojourner traverses and determine the best places to deploy the APX. The model was also used to help with long range rover path planning. A proposed traverse would be explored from a viewpoint at the height of the rover wheels to assess hazards. Once a traverse was planned, the target traverse could be stored using map markers. The heads-up display was used to retrieve local lander coordinates for targeting IMP imaging of particular features.

*Science Analysis.* The measurement and display capabilities of the VR model, along with the ability to reproject the image data to a new perspective, allowed normally difficult measurements to be made easily. During the mission, science team members used VR to measure the direction of over 300 small windstreaks which occurred behind rocks. These measurements were used to determine the prevailing wind direction [3]. The VR model was also used to measure the dimensions of over 2500 rocks at the landing site [3].

*Outreach.* During the Pathfinder mission, Marsmap was demonstrated hundreds of times to various individuals, groups, and members of the press who toured Pathfinder mission operations. The strong sense of presence afforded by VR gives it great public appeal.

**Further Developments with VR**: Subsequent to Pathfinder, we have created VR models using stereo cameras mounted on the Marsokhod rover. The 3-D models and user interface tools served were used for planning rover operations for a Mars rover mission simulation in Silver Lake, California in February, 1999 [4]. Image textures from orbital and descent images were overlaid on topography to produce a photorealistic 3-D model which was merged with that produced from the rover stereo cameras. This merged model allows the user to seamlessly transition from the orbital perspective to overhead views near the ground. Tools for obtaining and displaying altitude profiles and making area and volume measurements have been incorporated into the user interface.

**Conclusions:** This project has shown that VR can be used as a powerful method for analyzing the geology of a remote environment. VR models can be created and displayed and analysis and measurements can be performed with unprecedented speed and accuracy. Virtual Reality may represent a giant leap forward for cartography.

**References:**

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[3]Smith *et al*.(1997) J. Geophys. Res. 102, 4003-4025, 1997.
[4] Smith *et al*. (1997) Science 287, 1758-1770.