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Analyzing Pathfinder data using virtual reality and superresolved imaging

Carol R. Stoker, Eric Zbinden, Theodore T. Blackmon, Bob Kanefsky, Joel Hagen, Charles Neveu, Daryl Rasmussen, Kurt Schwehr, and Michael Sims
NASA Ames Research Center, Moffett Field, California

Abstract. The Mars Pathfinder mission used a unique capability to rapidly generate and interactively display three-dimensional (3-D) photorealistic virtual reality (VR) models of the Martian surface. An interactive terrain visualization system creates and renders digital terrain models produced from stereo images taken by the Imager for Mars Pathfinder (IMP) camera. The stereo pipeline, an automated machine vision algorithm, correlates features between the left and right images to determine their disparity and computes the corresponding positions using the known camera geometry. These positions are connected to form a polygonal mesh upon which IMP images are overlaid as textures. During the Pathfinder mission, VR models were produced and displayed almost as fast as images were received. The VR models were viewed using MarsMap, an interface that allows the model to be viewed from any perspective driven by a standard three-button computer mouse. MarsMap incorporates graphical representations of the lander and rover and the sequence and spatial locations at which rover data were taken. Graphical models of the rover were placed in the model to indicate the rover position at the end of each day of the mission. Images taken by Sojourner cameras are projected into the model as 2-D "billboards" to show their proper perspective. Distance and angle measurements can be made on features viewed in the model using a mouse-driven 3-D cursor and a point-and-click interface. MarsMap was used to assist with archiving and planning Sojourner activities and to make detailed measurements of surface features such as wind streaks and rock size and orientation that are difficult to perform using 2-D images. Superresolution image processing is a computational method for improving image resolution by a factor of $n^{1/2}$ by combining n independent images. This technique was used on Pathfinder to obtain better resolved images of Martian surface features. We show results from superresolving IMP camera images of six targets including near- and far-field objects and discuss how the resolution improvement aids interpretation. Similar flood deposits can be seen on both of the Twin Peaks that cannot be resolved in raw images. Millimeter-sized pits are resolved on the rocks Wedge and Halfdome. Other rocks at the Pathfinder site exhibit fine-scale layering that is otherwise invisible. Use of the method resulted in the probable discovery of an artifact of intelligent life on Mars: a part of the Pathfinder spacecraft.

1. Introduction

Pathfinder was the first rover mission to Mars, but it will not be the last. Rover missions are able to perform many of the functions of a field geologist [*Stoker*, 1996, 1998]. For example, a field geologist is able to look around, construct a mental three-dimensional (3-D) model of the nearby surroundings; perform measurements of nearby objects; determine slopes, strike, and dip of the distant terrain; and construct detailed maps of the region. The geologist also uses binoculars to get improved resolution of distant features, and a hand lens to get improved resolution of close features. In robotic missions, many of these capabilities can be simulated using the downlinked data from the rover and computers to reconstruct models of the terrain. Geologists can interact with these to accomplish many of the same things they would be able to do in the field.

In this paper we describe the recent application of computer graphics technologies to the Pathfinder mission. Photorealistic 3-D models of the terrain surrounding the Pathfinder lander were produced using stereo images from the Imager for Mars Pathfinder (IMP) camera. These 3-D models were displayed using an interface that allowed seamless real-time manipulation of the data. Using a head-tracked display, a user can experience a feeling of immersion in the 3-D model. Because the model is 3-D, interactive, and immersive, we refer to the model and display system in this paper by the term "virtual reality" or VR [*Aukstakalnis and Blatner*, 1992]. Another technique used on the Pathfinder mission was the automated production of superresolved images. This technique provided a virtual zoom lens for improved resolution of features of interest. Both technologies were used to enhance the understanding of the Martian surface and enabled geologic interpretation and analysis.

From early digital image processing techniques developed during the Viking era [*Levinthal et al.*, 1977; *Green*, 1977] to our application of photorealistic VR models to the Pathfinder landing site, advances in terrain modeling and visualization have closely followed advances in information technology.

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