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CONSTRUCTION OF A 3D MEASURABLE VIRTUAL REALITY ENVIRONMENT BASED ON GROUND PANORAMIC IMAGES AND ORBITAL IMAGERY FOR PLANETARY EXPLORATION APPLICATIONS

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ABSTRACT:

This paper presents a method of constructing a measurable virtual reality environment based on ground (lander/rover) panoramic images and orbital imagery. Ground panoramic images acquired by a lander/rover at different azimuth and elevation angles are automatically registered, seamlessly mosaicked and projected onto a cylindrical surface. A specific function is developed for inverse calculation from the panorama back to the original images so that the 3D information associated with the original stereo images can be retrieved or computed. The three-dimensional measurable panorama is integrated into a globe viewer based on NASA World Wind. The techniques developed in this research can be used in visualization of and measuring the orbital and ground images for planetary exploration missions, especially rover missions.

1. INTRODUCTION

Planetary exploration usually consists of orbital and lander/rover missions. Orbital images map the planet globally and provide geometrical and spectral information for landing-site selection, precision landing, and various scientific researches. Ground (lander/rover) images provide more detailed information of the landing site for daily mission operations such as close-up investigation of scientific targets. Visualization of these orbital and ground images and their derived products is essential to support mission operations and scientific researches, as well as education and outreach.

In earth observation and GIS fields, virtual reality (VR) and virtual geographic environments (VGE) technologies have been utilized for various applications (Lin and Gong, 2001). The concept of measurable virtual reality (MVR) was proposed and implemented based on seamless stereo-orthoimage database with digital stereo-orthophoto partner technique (Li et al., 2002). The concept and application of digital measurable images (DMI) in digital earth and geospatial information service have also been exploited (Li et al., 2008, 2010). GIS technologies have also been used in planetary exploration researches and operations, e.g., the Planetary Interactive GIS on-the-Web Analyzable Database (PIGWAD) developed by U.S. Geological Survey (Hare and Tanaka, 2000) and the OSU Mars WebGIS developed by the Ohio State University (Li et al., 2006). Overall, VR and MVR technologies have not fully studied and applied in planetary exploration applications.

As one of the most popular earth viewers, Google Earth (http://www.google.com/earth/) has included Moon and Mars orbital data, which enables users to fly anywhere on the Moon and Mars and view them from any view angles with multiple resolutions. Simple measuring functions such as length and heading are also provided. Panoramic images can be linked to the orbital images at locations where the panoramas were taken by lunar astronauts or Mars rovers. NASA World Wind (http://worldwind.arc.nasa.gov/), an open source earth viewer, has similar functions and includes more planets in the solar system. Overall, these viewers have very powerful and easy-to-use functions of viewing and browsing, but the measuring functions are limited, in particular, no measuring function is provided for panoramic images.

In this paper, we present a method of constructing a Measurable Virtual reality Environment (MVE) based on ground (lander/rover) panoramic images and orbital imagery. The MVE is implemented using ground panoramic images acquired by Spirit rover of the Mars Exploration Rover (MER) mission and HiRISE (High Resolution Imaging Science Experiment) orbital images of Mars. The technical details of the MVE construction method are given in the following sections.

2. CONCEPT OF MEASURABLE VIRTUAL REALITY ENVIRONMENT (MVE)

2.1 Concept of MVE

Figure 1 shows the conceptual diagram of the proposed MVE. Its core components include a panorama viewer and a globe viewer based on NASA World Wind. The three-dimensional (3D) measurable panoramas are constructed from ground stereo

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images through registration, mosaicking and projection onto a cylindrical surface. In particular, in order to enable 3D measurement functionalities in the panorama viewer, a specific function is developed for inverse calculation from the panorama back to the original images. The globe viewer is a platform for visualization and measuring of DEMs and orthophotos derived from ground and orbital images through 3D mapping procedures. Rover paths are also included in the globe viewer. The two viewers are interlinked and can be switched from one to the other. The MVE allows a user to visualize the orbital and ground images and maps from overhead view or the rover's view and measure 3D information easily.

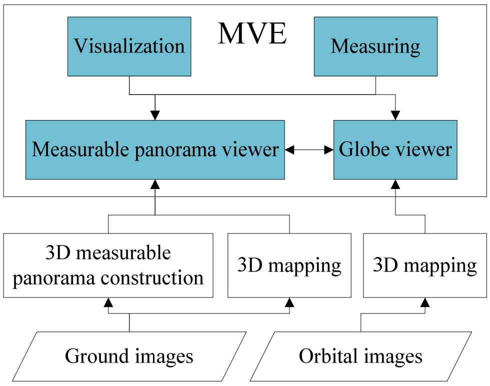

Figure 1. Conceptual diagram of MVE

2.2 Data

In this study, we use ground images taken by Spirit rover's Navcam (Navigation Camera) and Pancam (Panoramic Camera) and HiRISE orbital images covering the landing site of Spirit rover. The Navcam is a panchromatic stereo pair of engineering camera with 20 cm baseline separation (Alexander et al., 2006). The Pancam is a multispectral stereo pair of science cameras with 30 cm baseline separation. Both Navcam and Pancam are mounted on the camera bar, which can rotate ±90 degrees of elevation and 360 degrees of azimuth, enabling acquisition of panoramic images. The rover images have been pre-processed by the Jet Propulsion Laboratory (JPL) Multi-mission Image Processing Laboratory (MIPL) and products such as mosaics, linearized (epipolar) images, 3D coordinate data and range maps are also provided (Alexander et al., 2006). The derived 3D data sets, e.g., 3D coordinate data (XYL files) and range map (RNL files) are stored with the index of the left images of the stereo pairs. The images and the associated 3D data can be downloaded from the MER Analyst's Notebook website (http://an.rsl.wustl.edu/mer/mera/mera.htm), which is part of the Geosciences Node of the Planetary Data System (PDS). Figure 2 shows a pairs of linearized Pancam images.

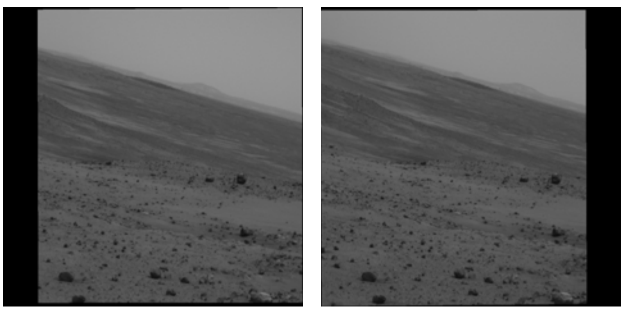

Figure 2. A stereo pair of Pancam images acquired by Spirit rover

HiRISE is a pushbroom sensor on board the Mars Reconnaissance Orbiter. It has an unprecedented high spatial resolution of up to 0.25 m/pixel, resolving objects below a meter across (McEwen et al., 2007). HiRISE images can be downloaded from the HIRISE webpage (http://hirise.lpl.arizona.edu/) or from the PDS website (http://pds.jpl.nasa.gov/).

3. PANORAMA MOSAICKING

Automatic construction of large, high-resolution image mosaics is an active area of research in the fields of computer vision, image processing, and computer graphics (Szeliski and Shum, 1997). Though some panoramic mosaics of rover images are provided in PDS, we build our own panoramic mosaic from linearized Navcam and Pancam images so as to enable 3D measurement functionalities.

3.1 Image pre-processing

In many cases, the rover traversed and stopped on slopes. This resulted in slanted horizons in the images. As a pre-processing step, horizon correction is performed using the images' exterior orientation parameters with the following equation:

$$\begin{cases} x' = x\cos\kappa - y\sin\kappa \\ y' = x\sin\kappa + y\cos\kappa \end{cases}$$

where (x, y) are the image coordinates of the original images, (x′, y′) are the coordinates of the horizon corrected image, κ is the rotation angle around the optical axis. Figure 3 shows an example image before and after horizon correction.

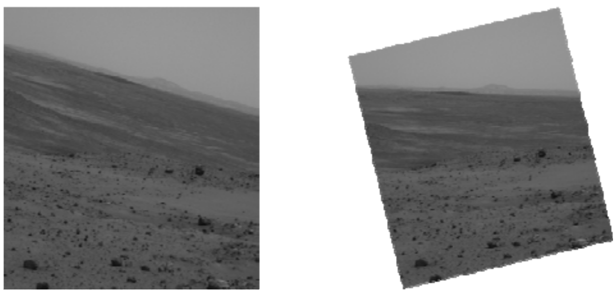

Figure 3. Horizon correction

3.2 Cylindrical projection

There are three commonly used projections for panorama construction: cylindrical projection, spherical projection and cube projection. In this paper, we focus on the cylindrical panoramas because of their ease of construction and good geometric characteristics. If the camera focal length or field of view is known, each perspective image can be warped into cylindrical coordinates easily (Chen, 1995).