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Using Stereo Photogrammetry to Create Digital Elevation Models of Planetary Surfaces

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Abstract

Stereo photogrammetry is a digital image processing technique that allows the user to obtain spatial measurements and determine geometrically reliable shapes of surface features from photographs or digital images of a planetary surface. In addition to many other outputs, photogrammetric processing generates elevation models containing terrain elevation and heights of objects on a planet's surface. Its main task lies in the reconstruction of three dimensional objects from two dimensional, plane photographs. This reconstruction of the third dimension requires overlapping aerial photographs in order to obtain stereo image pairs over the same area. On these stereoscopic pairs the change in the apparent position of an object due to the differing viewing geometry of topographic features will cause a parallax effect on the image that enables the calculation of 3D coordinates. In this project we are interested in creating digital elevation models (DEMs) of Mars, Europa, and other planetary surfaces using several software packages. The widespread use of DEMs and the importance they have assumed in many situations, derives from the basic elevation data they hold. Useful information they contain includes slope, aspect and visibility that may be computed from the elevation model, and many benefits result from the integration of the DEM with other geographic information. The main software package that we use to create the DEMs of interest is called SOCET SET. It is a photogrammetry software package developed by BAE Systems, and runs on a dedicated stereo photogrammetric workstation including dual polarized monitors for 3D image viewing. SOCET SET inputs digital aerial photographs, taken in stereo fashion, and from those photos it automatically generates a digital elevation model and orthorectified images. The output data is used to create digital maps, and for mission planning and targeting purposes. Accurate topographic profiles of features on planetary surfaces can be tested with results from geophysical models, and can provide important constraints on subsurface structure and thermal history of planets and satellites. For example, topographic models of chaotic terrain on Jupiter's moon Europa will be compared with new theoretical models of the formation of these features, and will provide information on the plausibility of these models. This research is supported by the NASA EPOESS grant "Undergraduate Research at the SETI Institute in Astrobiology." The work is being carried out at SETI Institute in Dr. Cynthia Phillips' imaging lab.

Keywords: remote sensing, planetary geology, digital elevation model

1. Introduction

In hopes to find out more information about the universe scientists invented many tools to achieve their goals. Nowadays, remote sensing and stereo photogrammetry are just a few of the many techniques that people use in their research about distant objects. With the above mentioned methods, people are able to obtain data about objects that are located far away without even touching them. With the help of photogrammetry, the geometric form of objects can be reconstructed, and the properties of a physical object can be obtained through remote sensing techniques. Stereo photogrammetry is a digital image processing technique that allows the user to obtain spatial measurements and determine geometrically reliable shapes of surface features from photographs or digital images of a planetary surface. Photogrammetric processing generates digital elevation models (DEM) containing terrain elevation and heights of objects on a planet's surface. Such topographic information is a necessary for almost every phase of research on planetary surfaces, as well as an essential tool for planning and operating spacecraft missions.[1] Accurate topographic profiles of features on planetary surfaces can be tested with results from geophysical models, and can provide important constraints on subsurface structure and thermal history of planets and satellites. For example, topographic models of chaotic terrain on Jupiter's moon Europa will be compared with new theoretical models of the formation of these features, and will provide information on the plausibility of these models.

2. Methodology

At the SETI Institute, the generation of DEMs requires special equipment that is illustrated in (Figure 1) and photogrammetric software that is called SOCET SET. In order to do stereo photogrammetry, it is necessary to obtain overlapping pairs of images of the desired surface. Most of the time, these images that were taken by spacecraft are available to the public on the World Wide Web. The best result is accomplished when the two images are a stereo pair. After downloading the desired raw images, the next step involves pre-processing them in the planetary image processing software called ISIS3. During this step, several Perl scripts have to be run in order to convert the raw images into another format that can be read by SOCET SET. After completing the pre-processing part, the two overlapping images are loaded into SOCET SET. The left and right images are being displayed on the stereoscopic displays labeled (a) and (b) in (Figure 1). Polarized glasses are used to restrict the left eye to view the bottom monitor and the right eye to view the top. Then, the human brain does all the work, so the overlapping images appear as one three dimensional image to the viewer. After loading the pictures, at least eight common points between the images must be found, while wearing the 3D glasses. These points, found in the overlap region of the two images are called "tie points." Tie points are necessary in order for the software to be able to execute the triangulation step, which registers images to the ground. After carefully picking eight or more tie points, the software has to solve for image parameters such as camera angles, location etc. using a least squares bundle

Figure 1. Workstation: (a), (b) stereoscopic displays (c) half mirror (d) 3D-topomouse (e) 3D passive glasses

block adjustment technique. During this step the image parameters need to be adjusted, so that the position of a point in one image corresponds to the same point position in the other. The RMS residual error is then calculated. Generally, if the RMS value is less than 2 pixels, then DEM of the overlap region can be created next. SOCET SET allows the user to pick an area from the overlapping region to create a DEM. The software is also able to generate orthophotos of the overlapping images. Orthophotos have all distortions removed. They represent what one would see if looking straight down at the ground from a far away distance above.

After the DEM and orthophotos associated with it have been exported from SOCET SET, ArcGIS software was used to extract terrain information from the DEM. ArcGIS is a geographic information system (GIS) for working with maps and geographic information. For example, at the very least, it is possible to calculate the height of any features on the planetary surface using ArcGIS tools.

3. Results

The method described above was used to create digital elevation models of Saturn's moon - Tethys and Jupiter's moon – Europa. The generated DEM of Tethys is illustrated in (Figure 2). So far, SOCET SET was not successful in generating a reliable DEM of any parts of Europa using the images taken by Galileo spacecraft.

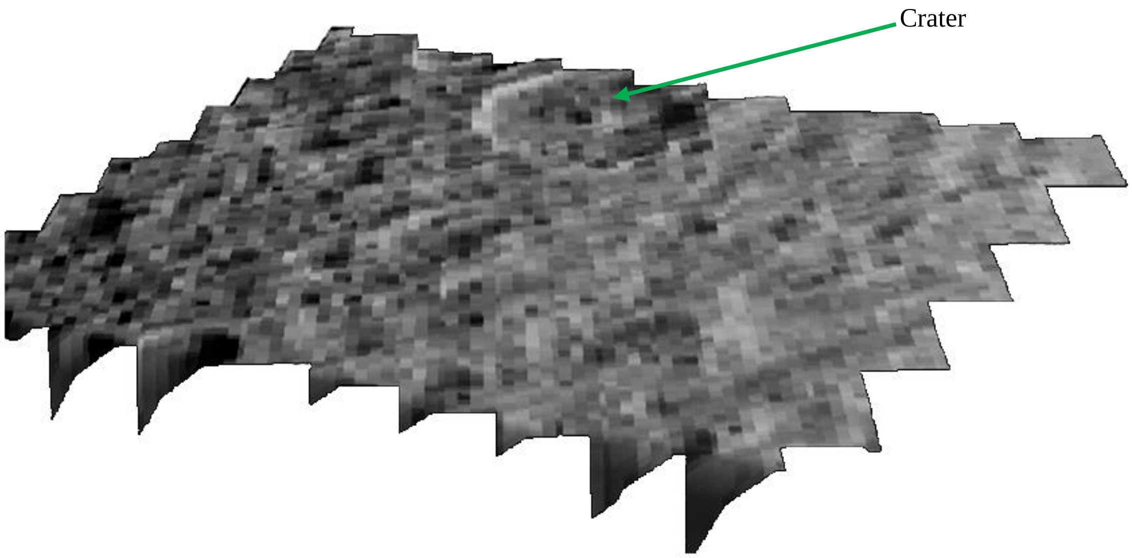

Figure 2. DEM of a crater on Saturn's moon - Tethys

4. Discussion and Future Work

A region of a crater located on Tethys was the only successful DEM that was created so far. When combined with numerical modeling, the topological profiles extracted from the DEM allow scientists to study Saturn's subsurface structure and thermal history.[2] The data is also used to test theoretical geophysical models. For example, it has been observed that over billions of years craters "relax" – meaning they reduce in depth. The study of the viscous relaxation of topographic features allows us to relate current surface topography to past subsurface structure and thermal profiles.[2] There are numerous models proposed to calculate the time it takes for the crater to "relax." The acquired profiles will allow us to measure the current depths of craters and will help us understand how they change over time.

However, our primary objective is still to create a DEM of chaos terrain features located on Europa (Figure 3). These features are known to be quasi-circular areas of ice disruption.[3] For example, one of the models suggests that chaos terrains on Europa are formed due to ice-water interactions and freeze-out.[3] According to Schmidt et al., chaos terrains form above liquid water lenses perched within the ice shell as shallow as 3 kilometers.[3] One of the most prominent chaos terrain features that we are hoping to study is called Thrace Macula, which is illustrated in (Figure 3). Unfortunately, because of the images taken by Galileo spacecraft, it was impossible to create a DEM of chaos features so far. Some of the factors that may have contributed to this misfortune are most likely the little overlap that images have, the huge resolution difference between the overlapping images, and basically the fact that the images by Galileo were not made for stereo work.

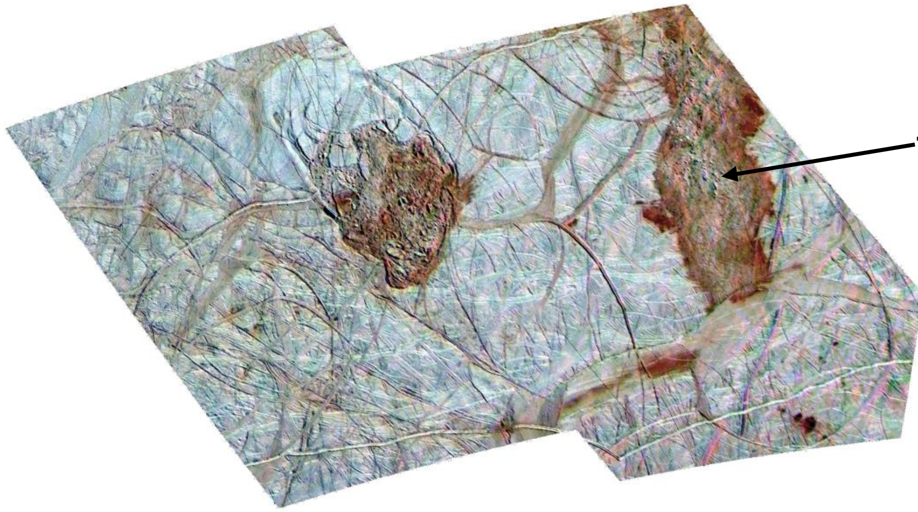

Figure 3. Thera and Thrace Macula chaos features located on Jupiter's moon - Europa

If a DEM of chaos terrain features on Europa were available, then the terrain data could again be used to test the validity of theoretical models of how these features formed in the first place and how they change over time. Besides testing theories, the results from DEMs can be helpful for locating important sites for future Europa spacecraft missions.

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