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PRECISION GEOMETRIC PROCESSING OF MINI-RF BISTATIC RADAR IMAGES OF THE MOON

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1. INTRODUCTION

This abstract is one in a series describing our development of techniques for radargrammetry (analogous to photogrammetry but taking account of the principles by which radar images are formed) and their application to mapping the Moon with Mini-RF images. Our overall goals are to use radar stereopairs to produce digital topographic models (DTMs) of medium resolution and broad coverage, and to control and orthorectify (project onto an existing DTM) images to produce image maps and mosaics with greatly improved positional accuracy. The previous abstracts in the series describe the general principles of radargrammetry and focus on the analysis of "standard" (monostatic) observations, which are obtained by transmitting and receiving the radar signal from the Mini-RF instrument in lunar orbit.

The present abstract focuses on bistatic observations, for which the transmitter is located on Earth and the receiver on the spacecraft. These observations are of tremendous scientific interest as part of the overall Mini-RF program of searching for ice deposits at the lunar poles because the variation of signal strength with the phase angle between transmitter and receiver may distinguish between coherent backscatter in ice and diffuse scattering by blocky surfaces. Controlling the bistatic observations so they are geometrically registered to topographic data and then orthorectifying them to remove parallax distortions are essential steps toward detailed and quantitative analysis. Only by these means can the bistatic polarimetry measurements be corrected for slope effects and correlated with monostatic radar images and other remote sensing data such as optical and thermal images and altimetry on a pixel-by-pixel basis.

2. SOURCE DATA

NASA's Mini-RF investigation consists of two synthetic aperture radar (SAR) imagers for lunar remote sensing: the "Forerunner" Mini-SAR on ISRO's Chandrayaan-1, which operated monostatically from 2008-2009, and the Mini-RF on the NASA Lunar Reconnaissance Orbiter (LRO), which carried out monostatic observations from 2009 until its transmitter failed in December 2010. The bistatic observations analysed here have been obtained exclusively by LRO, receiving signals transmitted from the Arecibo Observatory. Thirty-two bistatic observations have been obtained, and current operations include approximately two more per month.

Monostatic Mini-RF observations were processed by Vexcel Corporation into Level 1 (range-azimuth, where azimuth refers to distance along the flight track) and Level 2 (map projected) formats. The bistatic observations are being reduced by team members at Sandia National Laboratory. Initial products now in the NASA Planetary Data System (PDS) include raster images on a grid that is referenced to the spacecraft trajectory in a rather complex way. To facilitate precision processing, we are working to regenerate the bistatic observations in a map projection equivalent to that used in the monostatic Level 2 products.

3. TECHNICAL APPROACH AND METHODOLOGY

Precision geometric processing is based on a sensor model—a mathematical and software model capable of computing ground coordinates for a given image line-sample and vice versa—which can be used in multiple ways. For processing Mini-RF monostatic images, we developed a sensor model for Level 1 images in the USGS planetary cartography system ISIS, enabling us to orthorectify images by projecting them onto a DTM. By also computing how the ground position varies as a result of small shifts in the spacecraft trajectory (i.e., partial derivatives or "partials" of the coordinates with respect to trajectory adjustments), we can control the images by measuring image-to-ground correspondences and (for mosaics of more than one image) image-to-image ties, then using the bundle adjustment program *jigsaw*. Using LOLA as both ground truth and DTM thus allows us to produce mosaics in which pixels are accurately located regardless of topography and viewing geometry. In addition, we created a sensor model for the commercial SOCET SET stereomapping package, allowing us to produce DTMs at a useful resolution for regional mapping. Bistatic images provide little or no new stereo coverage; instead, their science value lies in the comparison of scattered power and polarization values with their monostatic (backscatter) equivalents. Our current work therefore focuses on the development of an ISIS sensor model for bistatic images to enable control by bundle adjustment and orthorectification.

4. SENSOR MODEL DIFFERENCES

Bistatic and monostatic radar images are similar to one another (and distinct from optical images) in that the fundamental observable coordinates of the images are the time of minimum range (zero Doppler shift) and the three-dimensional range ("slant range") at that time. Bistatic and monostatic images differ fundamentally in the geometric definition of range, however, and the Mini-RF files also differ in incidentals of how the images are presented. A prospective sensor model has to deal with both types of differences. Achieving this capability has required substantial work that will be of interest to photogrammetrists (and especially radargrammetrists), but the details are not crucial to most users because in the end the workflow will be identical to that for monostatic images. These details are omitted here for lack of space, but will be included in our poster.

5. STATUS AND FUTURE WORK

To date, we have demonstrated the capability to reprocess the bistatic observations on an Oblique Cylindrical map grid. We have designed PDS labels for such "Level 2" bistatic images and developed ISIS software to ingest image files in this format. We have also developed the software to fit the interpolating polynomials used for calculating time and range from pixel coordinates, and the sensor model transformations (ground to image and image to ground) making use of these polynomials.

The immediate next step is to create PDS Level 2 labels for a sample bistatic image in Oblique Cylindrical projection, ingest it into ISIS, and verify that the nominal ground coordinates (i.e., based on zero elevation and the nominal trajectory) match the coordinates calculated during image formation at Sandia. Once the sensor model has been validated by this step we will be able to orthorectify bistatic images in ISIS, but the results will only be useful in cases where the errors in the a priori trajectory are smaller than the image resolution. Otherwise the image will be projected onto the wrong part of the DTM and distortions will be increased rather than decreased. To address this problem, we are developing additional software to calculate the partials of the sensor model with respect to trajectory adjustments. Once this is done we will be able to use *jigsaw* to improve the alignment of the images with the LOLA DTM, based on measured point correspondences between the image and DTM. The result will be bistatic images (including all polarization information) that are aligned to sub-pixel accuracy to the topographic data and to the many monostatic observations that we are controlling separately. With these precision-geometry products, lunar scientists will be able to remove slope-related effects and compare the radar scattering behavior of the lunar surface on a pixel-by-pixel basis