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Radargrammetric Analysis of Mini-RF Lunar Images

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1. Introduction

This abstract is one of a series about our research and development of techniques for radargrammetry (the art and science of making geometric measurements based on radar images, analogous to photogrammetry but taking account of the different principles by which a radar image is formed). We previously described the software tools we have developed [1, 2], which allow us to make controlled image mosaics with positional accuracy more than an order of magnitude better than uncontrolled products, and to create high resolution digital topographic models (DTMs) from radar stereopairs even in areas not illuminated by the sun. Here, we describe the acquisition and processing of a targeted stereo observation of the equatorial zone, yielding a DTM of part of Jackson crater with very high horizontal resolution and vertical precision. It is unfortunate that the Mini-RF transmitter stopped operating in December, 2010 before additional targeted stereo observations could be obtained, because the resolution and swath width of the radar images occupy a "sweet spot" intermediate between the Narrow- and Wide-Angle Lunar Reconnaissance Orbiter Cameras [3], so that in addition to supporting geologic investigations such pairs would have been highly effective for filling in the gaps (on the order of kilometers at low latitudes) between LOLA laser altimetry profiles [4].

Our mapping of Jackson crater revealed significant long-wavelength geometric distortions in the DTM. Given the principles by which radar images are formed, such distortions cannot simply be instrument effects (like the optical distortions to which camera lenses are subject) but must arise from errors in the spacecraft trajectory data. We therefore report on our plans to assess the severity and frequency of these errors. This assessment is the first step toward identifying the cause of the problem and developing strategies both to correct the existing data and to ensure that future observations are affected as little as possible. Fortunately, one of the most effective ways to assess distortions in the majority of Mini-RF images simultaneously is by constructing the radargrammetric control network that would in any case be needed in order to produce controlled mosaics.

2. Instruments and data sets

NASA's Mini-RF investigation [5] consists of two synthetic aperture radar (SAR) imagers for lunar remote sensing: Mini-SAR (also known as "Forerunner"), which was launched on the ISRO Chandrayaan-1 orbiter in October 2008 [6], and the Mini-RF technology demonstration, which was launched on the NASA Lunar Reconnaissance Orbiter (LRO) in June 2009. The software and techniques described below are applicable to data from either instrument. Mini-SAR obtained nearly complete image coverage of both lunar poles to 80° latitude with a resolution of 150 m and radar wavelength of 12.6 cm (S Band), as well as images of non-polar targets for comparison purposes. LRO Mini-RF is capable of imaging in both S-Band and X-band (4.2 cm) wavelengths and at 150 m (baseline) and 30 m (zoom mode) resolutions. Most observations to date have been obtained in S-zoom mode. A combination of west- and east-looking coverage of part of the south polar zone in support of the LCROSS mission [7] was obtained in June-September 2009. Systematic S-zoom mosaics of both poles were obtained in June-July 2010. A second polar imaging campaign in November-December 2010 focused on X-band baseline imaging of the north pole, yielding >75% coverage before the instrument stopped transmitting. Substantial coverage of non-polar latitudes was also acquired, with >66% of the lunar surface covered in S band during 1.5 years of operations.

3. Technical approach

Our approach to radargrammetric processing of Mini-RF images [1, 2] follows the methods we have applied to numerous optical sensors and to the Magellan and Cassini radar imagers [9–11]. In particular, we use the USGS in-house cartographic software system ISIS [12] to ingest and prepare the data, project images onto a known reference surface, and perform general image analysis and enhancement tasks. We use a commercial digital photogrammetric workstation running SOCET SET (® BAE Systems) software [13] for DTM production by automated matching and for interactive editing of DTMs using its stereo display capability. We have written the software needed to translate the images and supporting information from ISIS to SOCET SET formats. In addition, we have written sensor model software (which allows one to calculate the line and sample image coordinates of any point whose latitude, longitude, and elevation are specified, or the latitude and longitude of any image pixel provided the elevation is specified; see [2] for details) for both ISIS and SOCET SET. As a result, we can use either system to perform a bundle adjustment that improves the registration of Mini-RF images to one another and to ground control, and to project the images onto a topographic surface, and have verified [1, 2] that consistent results are obtained. The tools needed to create DTMs are, however, unique to SOCET SET. This commercial software package is relatively expensive, but the USGS makes it available as a guest facility at which outside researchers can make their own DTMs from released data [14].

4. Targeted stereo at Jackson crater

Stereoanalysis of images from a systematic mapping campaign that are obtained with a constant look angle is hampered by the tradeoff that as the image overlap increases, the strength of the stereo geometry (for same side imaging) decreases. Combining images with opposite look directions avoids this problem, but matching such images is more difficult because they will also be oppositely illuminated. One way to avoid these problems is to obtain two same-side images at different look angles. To test this idea, stereo observations of the 71-km crater Jackson were targeted on 25 April 2010. On orbit 3821, latitudes 7.5°S to 40°N near longitude 196°E were imaged with the normal off-nadir look angle, resulting in a centerline incidence angle of 44°–48°. On the following orbit, the same area was imaged at a reduced incidence angle of 24°–29°. Each observation was obtained in four segments, corresponding to the changing target elevation. We restricted our processing to the first segment of each image to cover the crater. Controlling the images was difficult because of substantial overall discrepancies in elevation between the stereo model and the LOLA DTM used as a control source. We resorted to a solution tied to LOLA by only a single well-defined ground point on the northern crater rim, with tie points distributed along the image strip. This was sufficient for stereo matching to proceed very effectively, yielding a DTM at 25 m/post grid spacing. Only minor editing was required, mostly near the image edges; the normalized editing time of ~0.8 hours per million DTM points compares favorably with HiRISE images [15] and is dramatically less than required for other radar data [11]. The DTM reveals details of crater morphology such as the central peak and terracing of the inner wall down to ~50 m in horizontal scale.

Comparison of the stereo DTM with ~250 m/post LOLA grid data revealed (in addition to dramatically greater detail) a very smooth discrepancy that varied almost quadratically with latitude and had a peak-to-peak amplitude of nearly 4000 m. In addition, the bundle adjustment residuals in the north-south direction were ~3x higher than for the image set in Cabeus crater that we had previously controlled [2] and these residuals also varied systematically as a smooth, almost cubic function of latitude having a peak-to-peak amplitude of 6 pixels (~90 m). Because radar images are formed by measuring the location of features in relation to the spacecraft trajectory (i.e., time of zero Doppler shift and range at that time) these distortions and discrepancies in the calculated ground coordinates must come from errors in the trajectory data used at some stage in processing.

5. Next steps

Determining how widespread such trajectory errors are, what causes them, how they can be avoided, and whether and how they can be mitigated for images already taken is now the main focus of our work. We are pursuing, and will report on, several lines of investigation:

1. Joint bundle adjustment of the Jackson crater Mini-RF images with optical images from the Lunar Reconnaissance Orbiter Narrow Angle Camera (LROC-NAC, 0.5 m/pixel [3]), which should allow us to determine whether the distortions are present in both or only one radar image;
2. Collection of DTMs from additional polar and non-polar image pairs; and
3. Compilation of a control network for the lunar poles, consisting of automatically measured tiepoints between overlapping Mini-RF images, plus a smaller number of manually measured ground control points. Bundle adjustment of these networks will rapidly screen a large number of Mini-RF images for unexpected geometric distortions.

In addition to contributing to the diagnosis of the image distortions found at Jackson crater, the new DTMs will be of substantial scientific value in addition to testing for the presence of major image distortions. The polar control networks will pave the way for production of controlled radar image mosaics with pixel-level precision and accuracy, which will be invaluable in the correlative study of lunar polar geology and the putative ice deposits.

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