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Calibration and Mosaicing of SMART-1 Images

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Abstract

Since mid 2010 the scientific community has access to the data collected by SMART-1 mission that orbited the Moon between 2004 and 2006. The onboard camera (AMIE) collected during that period images with the then state-of-the-art resolution and coverage of the lunar surface. The scientific interest of SMART-1 images is historical, as the data offers a snapshot of the lunar surface during the mission period, allowing comparative studies of the lunar surface. Our aim in this work is to build the atlas of the Moon as SMART-1 captured it. During the Earth escape phase, the AMIE CCD was damaged by radiation, invalidating the laboratorial flat field correction algorithm. A new image calibration procedure was developed based on the in-flight images and on theoretical models. This was followed by a mosaicing technique applied to all the 31947 collected images , to select, compensate geometrical distortions and compose a total of 88 maps of the lunar surface.

1. Introduction

Small Mission for Advanced Research and Technology (SMART-1) was the first European Space Agency (ESA) mission to place a satellite in lunar orbit [1]. The spacecraft orbited the Moon between November 2004 and September 2006, when the mission ended with a planned impact onto Lacus Excellentiae. The spacecraft carried onboard three scientific instruments for lunar research: an ultra-compact electronic camera to survey the lunar terrain in visible and near-infrared light (AMIE), an infrared spectrometer to analyze the lunar surface mineralogy (SIR) and a X-ray spectrometer to identify key chemical elements on the lunar surface (D-CIXS). On September 2010, the complete 3-year datasets archives from SMART-1 mission instruments were released to the scientific community.

The objective of this work is to produce a complete high resolution map of the Moon with AMIE images. The AMIE CCD was divided into 6 filter areas, with four spectral bands at wavelengths of 750, 847, 915 and 960 nm (with the filters directly in front of the CCD), and a non-filter area capturing visible light [1].

2. Image calibration

The image calibration procedure prepared prior to mission launch was deprecated due to the high amount of radiation the camera was exposed to during flight which changed the image capturing quality. Consequently, there was an increase of dark current and charge accumulation on top of the CCD, requiring a new calibration using *in-flight* data.

The calibration (Fig. 1) begins with the application of a brightness scaling factor that compensates for the illumination conditions by homogenizing the brightness. This procedure uses the general formulation of the Hapke's surface function. After scaled and, with new dark images captured from dark sky observations taken during the mission, the dark current component is removed and a horizontal 7x1 pixel median filter for the cleaning of noisy vertical lines is then applied. The calibration finishes with the application of the flat field compensation, with new master flat field images created by averaging a large number of images, for intensity balance and image harmonization.

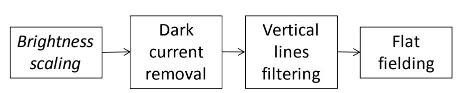

Figure 1: Calibration sequence.

3. Image Selection

The calibration process reduces the intensity and contrast difference between the filtered and non-filtered areas of the sensor. However, the different sensitivity of the various areas on the CCD sensor created a large number of partially under- or over-exposed pictures that needed to be manually classified before the image mosaicing. Four classes were considered (*unusable*, *only non-filter area*, *only filter area*, *full frame*), which resulted on 21434 full frame images, 3488 unusable images, and for the 7025 remaining only partial images can be used.

4. Image Mosaicing

The image mosaicing procedure enables to adequately display on each map the set of images with area intersecting the map to be created, according to the geometry calculated for each image.
The method starts (fig. 2) by using the SPICE system developed by NASA [2] to compute the geometry of the acquired image based on spacecraft and Moon dynamics information. The images are then prioritized in order to obtain a visually attractive map. We give priority to images with: highest possible resolution, adequate illumination (incidence angle neither too low or too high) and homogeneous illumination (all the images to be included on the same map should be homogeneously illuminated). Finally, the projected image is calculated by accumulating the contributions of all projected pixels. Although to project pixels in true integer coordinates forward warping with distance interpolated splatting [3] is required to fill all destination pixel locations. This technique spreads the pixel values to the intermediate locations with a weight that is inversely proportional to the distance to the original pixel location, similarly to an interpolating technique.

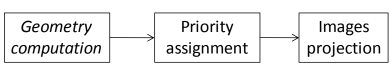

Figure 2: Image mosaicing process main steps.

5. Moon Atlas Organization

The Moon atlas was organized in 88 square maps covering the entire lunar surface. The lower latitudes (between 75° S and 80° N) are represented in Mercator projection (Fig. 3), while the poles are represented with stereographic projection (Fig. 4).

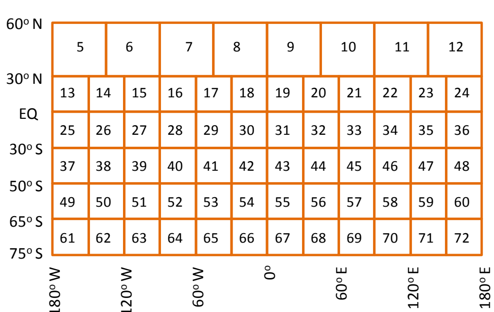

Figure 3: Mercator maps layout.

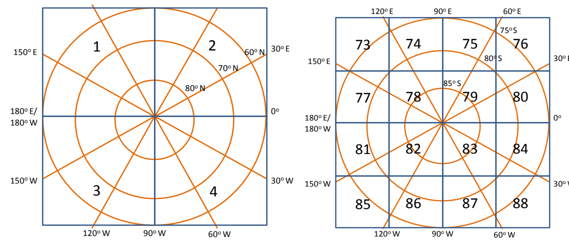

Figure 4: North Pole and South Pole layout.

6. Summary and Conclusions

In this work, an image processing work-flow has been developed which creates an image mosaic of 88 maps of the lunar surface using the 31947 images acquired by AMIE camera during the SMART-1 mission
The lower latitudes are documented with a resolution varying between 300 and 100m/pixel, increasing towards the South Pole. For the North Pole, the available resolution is lower with typically 270m/pixel and was divided in four 300m/pixel maps. The South Pole, where typical image resolution is 27m/pixel, was divided into 16 maps each with a resolution of 75 m/pixel [4], [5]. At the current stage of development the maps achieved a good resolution, varying according with the resolution available, they show a good visual transition between adjacent images and have near to 96% Moon surface coverage. The future improvements on the image processing methodology are expected to lead us to publish a Moon Atlas, although of historical relevance, with significant scientific potential. The camera AMIE measured specific targets to study geophysical and geochemical processes (cratering, volcanism, tectonics, erosion, deposition of volatiles) for comparative planetology.

References

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