



SMART-1

AMIE

Advanced Moon micro-Imager Experiment

The offset between AMIE images and the Clementine basemap

Björn Grieger

SCI-OS

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1 General items

1.1 Scope

The SMART-1 SC contains a number of scientific instruments, a few of them being remote sensing instruments. One of them is AMIE, a camera with 5.4° field of view and a total of 8 fixed filters in front of its CCD detector. This report addresses considerable offsets which have been reported to occur between AMIE images projected onto the Moon's surface and the Clementine basemap.

1.2 Introduction

Based on the SPICE kernels for the SMART-1 spacecraft and for the AMIE instrument, SPICE can be used to project the AMIE images onto the Moon's surface. As reference for the AMIE images, the AMIE team uses the Clementine basemap, which has been compiled by the USGS from images taken by the Clementine SC. Particularly by AMIE team members from l'Observatoire de Paris, considerable offsets between the AMIE images and the Clementine basemap had been reported. These offsets had at least partly been caused by erroneous preliminary versions of the instrument frame kernel. A new kernel 'SMART1_V1.TF' was prepared by SCI-OS and thoroughly tested, see [S1-AMIE-RSSD-TN-008]. The kernel passed successfully various tests, also the projection

of an image onto the Moon's surface and a comparison with the Clementine basemap.

However, the particular test of projecting an image onto the Moon was only conducted for one single, more or less randomly selected image. For other images, the AMIE team members from l'Observatoire de Paris saw still offsets from the Clementine basemap, even with the new kernel. Also at SCI-OS, where many images have been compared with the Clementine basemap in the course of sorting out problems with the non-monotonic sequence of images in the DDS, considerable offsets have been found. Herein, we quantitatively investigate these offsets and demonstrate that they are in line with properties of the Clementine basemap described in a presentation by A. C. Cook and others given at the AGU 2002 Fall meeting [Cook-2002].

1.3 Brief summary of results

Our findings are the following:

- The boresight of the AMIE images as mapped to the Moon's surface based on the current SPICE kernels is correct. The offsets between AMIE images and the Clementine basemap are caused by inaccuracies of the Clementine basemap.
- While the boresight is mapped correctly onto the Moon, a slight rotation around the viewing axis with respect to the Clementine basemap can be observed. This is due to an inaccuracy of the instrument frame kernel. However, the positioning error of an image pixel due to this rotation is much smaller than the typical offset of the Clementine basemap.

1.4 Reference documents

- [Cook-2002] Preliminary Analysis of the Absolute Cartographic Accuracy of the Clementine UVVIS Mosaics (<http://astrogeology.usgs.gov/Teams/Geomatics/geodesy/davies.html>)
- [S1-AMIE-RSSD-TN-004] AMIE boresight analysis (Iss./Rev. 1a, 2007-Feb-28)
- [S1-AMIE-RSSD-TN-008] Test of the AMIE frame kernel V1 (Iss./Rev. 1/-, 2007-Jul-03)

1.5 Abbreviations

AGU	American Geophysical Union
AMIE	Advanced Moon Imaging Experiment
CCD	Charge Coupled Device
DDS	Data Distribution System
FOV	Field Of View
SC	Spacecraft
SPICE	Spacecraft, Planet, Instrument, Camera-matrix, Events
USGS	United States Geological Survey

2 Matching AMIE images to the Clementine basemap

2.1 Projecting the images onto the Moon's surface

In a first step, we created low resolution (128×128 pixel) versions of the images. For each pixel (of such a low resolution image), we compute its location on the Moon using SPICE. The lower resolution is still sufficient for a comparison with the Clementine basemap, and it considerably reduces the data volume and the loading time.

2.2 The set of investigated images

The selection of the images we looked at was to some extent randomly. We started out with the images of which we already had created low resolution versions in the course of sorting out problems with the non-monotonic sequence of images in the DDS. Then we looked for orbits to fill the largest gaps. In total, we matched 395 images from the orbits 577, 700–761, 872, 1506–1518, 1542–1578, and 2735.

2.3 Matching images to the Clementine basemap

We have computed latitude and longitude of each pixel of an image (section 2.1). To match the image to the Clementine basemap, we visualize the basemap in simple (equidistant) cylindrical projection and overlay the AMIE image on top of it. By blinking the AMIE image on and off, we recognize any offset from the basemap. Then we shift the AMIE image in latitude and longitude until it matches the basemap. We record the applied shift. A table of all values found is given in appendix A.

Our adjustment takes place in steps of 0.05° in latitude and longitude. As the typical offset is a few tenths of a degree, this is a reasonable compromise between accuracy and time effort.

The shift is applied uniformly in latitude and longitude to all pixels. This is strictly correct only at the equator. At higher latitudes, such a simple shift without re-projection of the individual pixels causes rotation and distortion. However, as the shifts are quite small, the errors are negligible until we get really close to the poles. In fact, we noticed a slight rotation which we first attributed to this effect, but later we noticed that it persists down to the equator.

Therefore the observed rotation is *not* due to our simplified shifting procedure, but to a small inaccuracy of the instrument frame kernel, cf. section 4.

2.4 Visualization of the offsets

From the shifts in latitude and longitude in degree, we compute the magnitude of the offset in km. The result is shown in Fig. 1. We notice a strong consistency

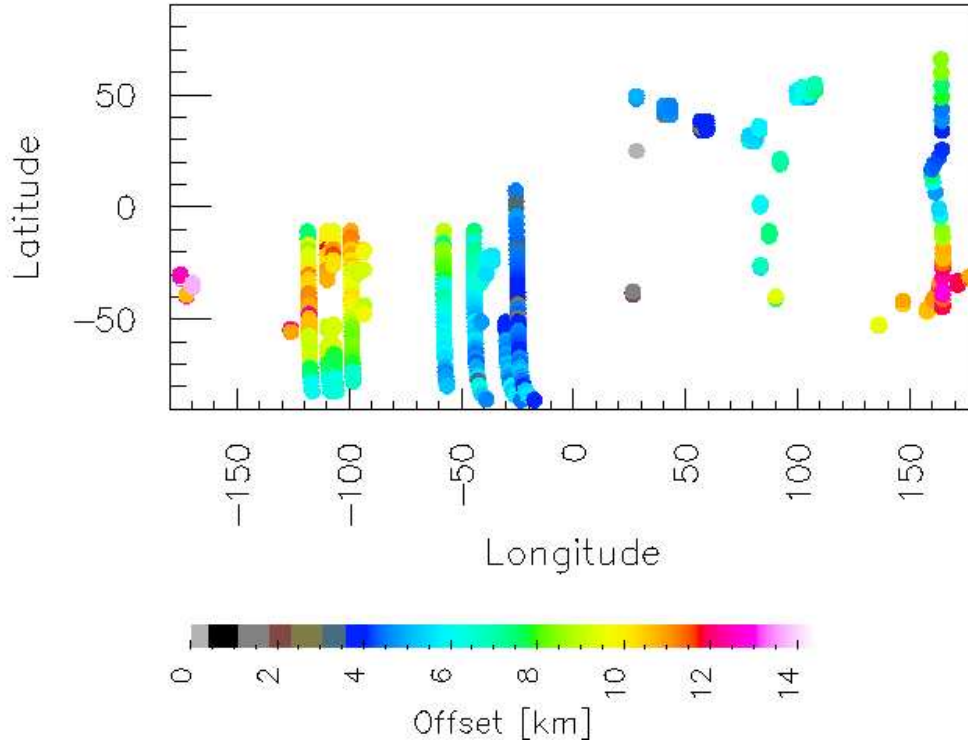


Figure 1: Magnitude of the offsets between AMIE images and the Clementine basemap. Each dot represents one image.

between different orbits, thus the offset from the Clementine basemap depends clearly on the location on the Moon.

Of the 395 images investigated, the one with the smallest offset (in fact the offset is zero with our accuracy of 0.05°) can be seen at 28.2° N, 25.0° E. And this is just the one image that had more or less randomly been picked for the instrument frame kernel test (cf. section 1.2), (miss-)leading to the conclusion that the match of the AMIE images with the Clementine basemap is fine.

3 Cartographic accuracy of the Clementine UVVIS mosaic

3.1 Spurious deviations of the Clementine mosaic

A preliminary analysis of the accuracy of the Clementine basemap was presented in [Cook-2002]. The authors note considerable differences between the original location of the Clementine images on the Moon as determined from the archived SPICE kernels and the control network resulting from the USGS' effort to create the mosaic. While they find good agreement in the 'Apollo zone' (comparable to the pointing accuracy of the SC of the order of one kilometer), they find about 10 times larger deviations in other areas. The authors offer the explanation that only in the 'Apollo zone' absolute positioning control is available and that the mosaicing process builds up large errors away from this zone. They strongly question whether it is reasonable to allow positioning differences much larger than the pointing accuracy. A map illustrating the differences is shown in Fig. 2.

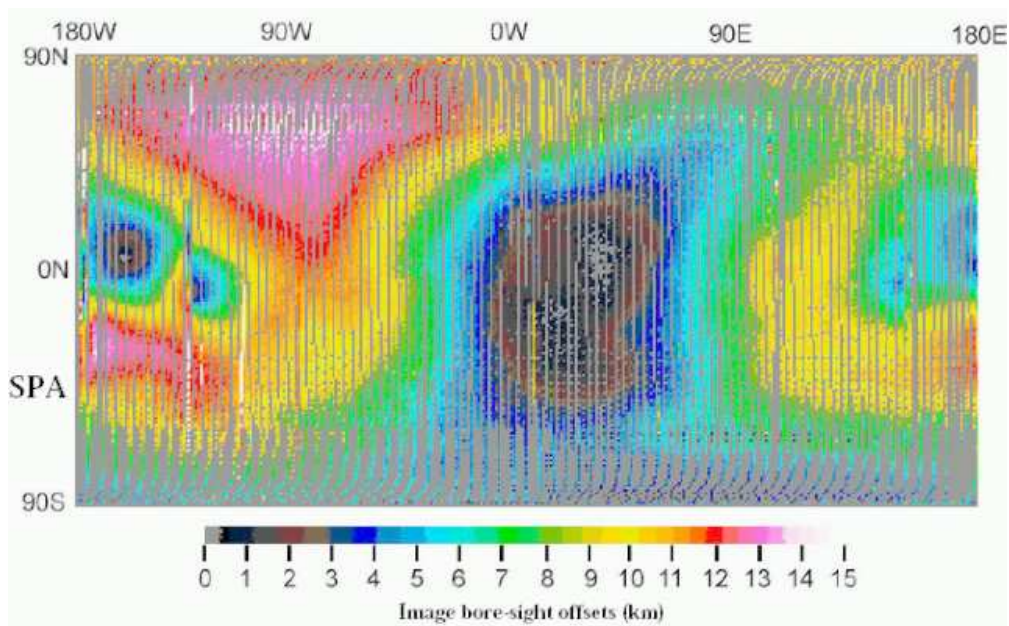


Figure 2: The differences between Clementine image centers projected onto the Moon according to the archived SPICE kernels and the USGS control network resulting from the mosaicing process in which the basemap was created.

3.2 Comparison of Clementine basemap deviations and AMIE offsets

If we compare the map of erroneous deviations of the Clementine basemap mosaic from the original image positions (Fig. 2) with the map of AMIE offsets

from the Clementine basemap (Fig. 1), we notice a very good agreement. From this we can conclude that the considerable offset of the AMIE images from the Clementine basemap is caused by inaccuracies of the Clementine basemap itself. The AMIE pointing information given by the SPICE kernels is correct, at least any error is much smaller than the observed offset from the Clementine basemap.

4 Small erroneous rotation around the line of sight

4.1 Preliminary estimation of the rotation

While manually matching the AMIE images to the Clementine basemap (section 2.3), we noticed a small rotation of the former with respect to the latter. This rotation looked very similar for all images which we investigated. We exemplify this rotation with image ‘AMI_LE?_R01506_00027_00012.IMG’ (with ‘?’ representing the filter numbers 1–8) in Fig. 3. This example image has been matched to the basemap with a higher accuracy of 0.01° rather than the 0.05° used for the bulk of images (cf. section 2.3). The small rotation of about 1° clockwise is hardly visible in the static images. We have marked some features on the Clementine basemap with green control points. These control points do not exactly fit the same feature in the AMIE image. After a clockwise rotation of 1° , the control points (the rotated set now marked in red), do reasonably fit the features in the AMIE image, at least better than without rotation. The rotation can much easier be recognized when blinking on and off the overlaid AMIE image.

4.2 Relation to the AMIE instrument frame kernel

We attribute the observed rotation to an inaccuracy of the AMIE instrument frame kernel. Such a small residual rotation around the boresight does not come as a surprise. The current frame kernel ‘SMART1_V1.TF’ is derived from the AMIE boresight analysis [S1-AMIE-RSSD-TN-004] which was based on the observation of a single star. This observation does not completely constrain all three angles of rotation which describe the camera orientation. It was known that the rotation around the line of sight implied by the kernel is not well constrained. The found rotation with respect to the Clementine basemap confirms the need for a refined boresight analysis based on multiple star observations.

A Table of the offsets found

The following table lists the offsets found for all investigated AMIE images as described in section 2.3. Each record belongs to one image. After the ‘ECHO’ starting the record, there are four columns:

1. Longitude in degree of the (full frame) boresight
2. Latitude in degree of the (full frame) boresight

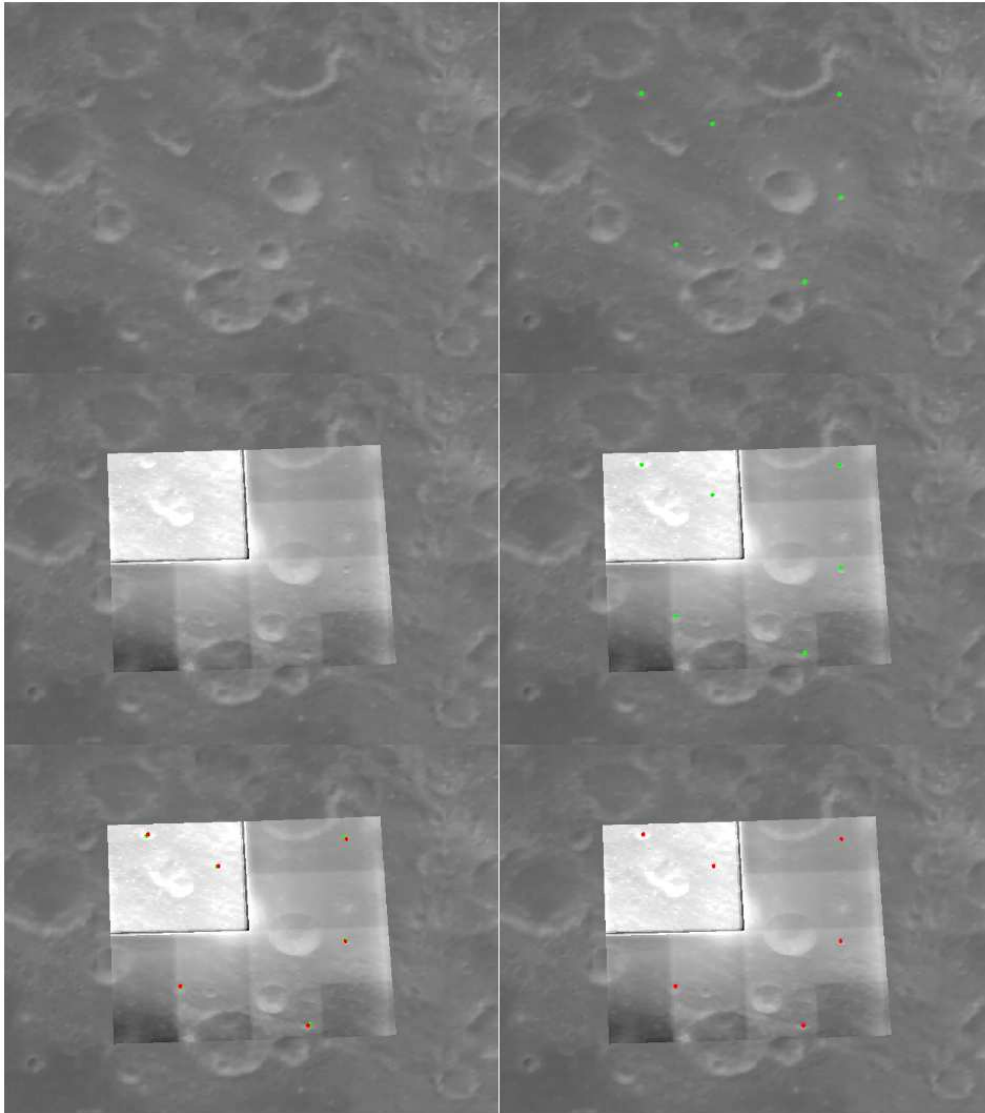


Figure 3: Demonstration of the rotation of the AMIE FOV. Top left: Only Clementine basemap. Top right: Clementine basemap with control points marked in green. Center left: AMIE image on top of Clementine basemap, already matched to basemap by shifting 0.14° eastward and 0.06° northward. Center right: AMIE image with the original control points. Bottom right: AMIE image with control points rotated 1° clockwise around the boresight, marked in red. Bottom left: AMIE image with both, unrotated and rotated control points.

3. Shift in longitude in degree

4. Shift in latitude in degree

The shifts give the values which have to be added to the AMIE co-ordinates to make the image match the Clementine basemap.

```

ECHO:  -17.3959  -85.8939  1  0.1
ECHO:  -20.1196  -83.8137  1  0.15
ECHO:  -21.4493  -81.7569  1  0.1
ECHO:  -22.2477  -79.6988  0.5  0.1
ECHO:  -22.7824  -77.6368  0.5  0.1
ECHO:  -23.1655  -75.5781  0.5  0.1
ECHO:  -23.4591  -73.4822  0.5  0.1
ECHO:  -23.684   -71.4304  0.4  0.1
ECHO:  -23.8648  -69.3878  0.3  0.1
ECHO:  -24.0141  -67.3501  0.3  0.1
ECHO:  -24.1415  -65.2842  0.2  0.1
ECHO:  -24.2501  -63.2279  0.2  0.1
ECHO:  -24.3421  -61.2208  0.2  0.1
ECHO:  -24.424   -59.1898  0.2  0.1
ECHO:  -24.4963  -57.1713  0.2  0.1
ECHO:  -24.5606  -55.1675  0.2  0.1
ECHO:  -24.6184  -53.1795  0.2  0.05
ECHO:  -24.6705  -51.2079  0.2  0.05
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ECHO:  -24.7597  -47.3906  0.2  0.05
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ECHO:  -24.9625  -35.9751  0.15  0.05
ECHO:  -24.9901  -34.045   0.15  0.05
ECHO:  -25.0173  -32.0389  0.15  0.05
ECHO:  -25.0439  -29.96   0.15  0.05
ECHO:  -25.0691  -27.8814  0.15  0.05
ECHO:  -25.094   -25.7042  0.15  0.05
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ECHO:  -25.141   -21.1829  0.15  0.05
ECHO:  -25.1628  -18.8463  0.1  0.05
ECHO:  -25.1844  -16.4334  0.15  0
ECHO:  -25.2354  -13.8537  0.15  0
ECHO:  -25.314   -11.0102  0.15  0
ECHO:  -25.4006  -7.87249  0.15  0
ECHO:  -25.4817  -4.40523  0.15  -0.05
ECHO:  -25.5578  -0.4899  0.1  -0.05
ECHO:  -25.613   2.33953  0.1  -0.05

```

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