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SPA.2013.2.1-01 - Analysis of Mars Multi-Resolution Images using Auto-Coregistration, Data Mining and Crowd Source Techniques

- Collaborative project -

D4.4
Auto Co-Registration of NASA datasets to HRSC

WP 4 – Global DTM/ORI production & validation

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History table

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Executive Summary

This report summarises the co-registration and orthorectification processing that was conducted within the iMars project. A short description of the pipelines used for this processing is followed by statistics about the achieved results, their accuracy, as well as the computational time required for this processing. A short summary regarding the work that is not yet finished but is planned to be included in the final report of the project concludes this short report.

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Key word list

Multi-instrument co-registration, Geometric Alignment, Batch-Mode Processing

Definitions and acronyms

DTM	Digital Terrain Model
HRSC	High-Resolution Stereo Camera
CTX	ConText Camera
MOC-NA	Mars Orbital Camera – Narrow Angle
THEMIS-VIS	Thermal Emission Imaging System - Visual
ORI	OrthoRectified image
ESA	European Space Agency
NASA	National Aeronautics and Space Administration
ACRO	Automatic Co-registration and Orthorectification
SPRC	South Pole Residual Cap
ISIS	Integrated Software for Imagers and Spectrometers

1. Introduction

This report summarizes the work that was done during the iMars project to co-register high-resolution (≤100m/pixel) NASA imagery to ESA's HRSC baseline of level-4 ORIs (12.5-25m/pixel) and DTMs (50-150m/gridpoint). This processing was conducted using a fully automatic pipeline, named ACRO for Automated Co-Registration and Orthorectification, which was developed within the iMars project and is further described in D2.1 and D2.2. This pipeline uses as an input a level-1 image to be co-registered and the corresponding HRSC DTM and ORI, and the georeferencing information which is used to guide the geometric alignment of the input image. The ACRO algorithm is fully automatic, i.e. it doesn't require any parameter determination to initiate the processing. This allows the use of the pipeline in a batch-mode, in which a list of images that overlap with a single baseline is sequentially (and independently) processed. Note that the overlapping baseline can be estimated from the original georeferencing information of the input image, since the mis-registration errors are typically in the order of hundreds of metres (rarely exceed 1km). Therefore, it can be used for an approximate estimation of the image position.

During the iMars project, 6 different variations of ACRO pipeline were developed and applied:

- ACRO v0.1, was the originally prototype, used for debugging, preliminary experimentation and validation of the algorithm. It is described in D2.1 and D2.2 and in [1]. This algorithm was used as a starting point to build pipelines that can achieve the co-registration and orthorectification of high-resolution imagery, but it was not used, per se, to do any iMars related processing.
- ACRO v1.0, the first version of the ACRO pipeline was used to co-register all CTX, MOC-NA and THEMIS-VIS images covering MC11-E. In this version, suitable metadata were added to the pipeline output (agreed between UCL and FUB), which would facilitate the ingestion of the processed products into the iMars webGIS, as well as building footprints for each processed image. Finally, the products were projected to equirectangular projection, following the projection adopted by the HRSC MC11-E mosaic.
- ACRO v2.0, improved some issues that were identified during the processing with ACRO v1.0 pipeline, while allowing an easier update of the pipeline for different types of input. More specifically, the algorithmic improvements were both in accuracy and computational cost, while the pipeline setup changed allowing easier adjustments of the pipeline to different geometric projections and baseline input. ACRO v2 is the main current co-registration and orthorectification pipeline used in iMars processing images from MC11-W and with variations to process images over the rest of the planet, including the SPRC.
- ACRO v2.1, a variation of the ACRO pipeline ACRO v2.0 to single-strips baseline in non-polar regions. The main updates in this version were firstly, the use of the sinusoidal projection (as used by the HRSC team for their single-strip products in latitudes less than 85 degrees) and secondly, an adjustment in the

baseline ingestion to the pipeline to improve the speed of the processing. Note that ACRO v2.0 has a slower baseline ingestion, but with less memory requirements, because the released HRSC MC11 mosaics have such a large size that adjustments to limit the required memory are necessary. This version was used for the processing of images from regions that HRSC mosaics were not available and only level-4 HRSC DTM and ORI single strips were available.

- ACRO v2.2, a variation of ACRO v2.1 to single-strip baseline over polar regions, i.e. using polar stereographic projection. This pipeline is used to process images from the SPRC.
- ACRO v2.3, a variation of ACRO v2.0 in which the baseline different from HRSC is used to process (usually low-quality) images that initially failed to be co-registered successfully. The rationale behind this development was that single-instrument co-registration (i.e. co-registration in which the input and the baseline originate from the same spacecraft instrument) is typically “easier” than multi-instrument co-registration (i.e. co-registration in which the input and the baseline originate from different instrument or/and from different spacecraft), i.e. it is more accurate, more reliable and faster. Therefore, the imagery that initially failed to be co-registered using ACRO v2.0, v2.1 and v2.2 were re-processed using as a baseline (where available) images of the same instrument that were successfully processed (using HRSC baseline) in a previous iMars related run. Often CTX was used as this surrogate.

The connections of the ACRO pipelines used within iMars are shown in Figure 1. In the rest of this report, we will summarise the processing that was done with each of these pipelines.

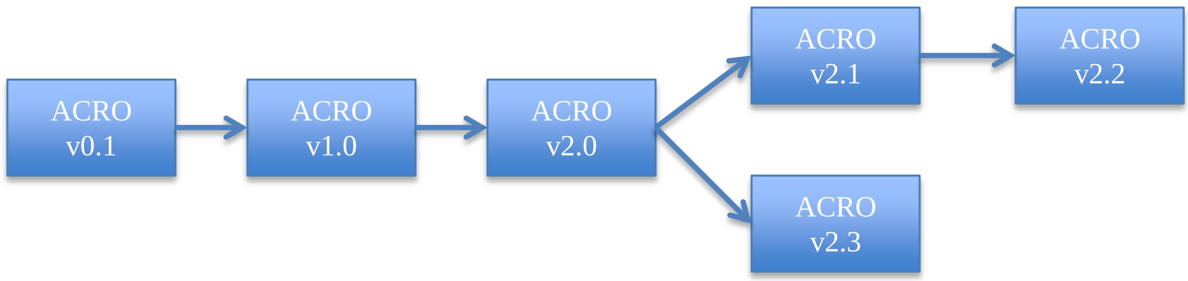

Figure 1. The ACRO versions used within iMars.

2. Automatic co-registration and orthorectification

2.1 ACRO v1.0

The first version of the automatic co-registration and orthorectification pipeline was the first version of the algorithm that was used to process large volumes of multi-instrument data without requiring human intervention. The pipeline was tailored to the specifications of the MC11-E mosaic that was released by the HRSC team [2], [3], using the HRSC MC11-E projection and central longitude as hard-coded parameters. The goal of this run was not only to produce the first results to be used within iMars but also to test in anger all stages of the processing. The initial processing (finished in

December 2015) was terminated due to photometric consistency reasons (all products were using their own grey-scale range, thus making them incompatible with each other, which would have adverse effects on the change detection pipelines of the project), and all images were subsequently re-processed and disseminated throuh the iMars webGIS in June 2016.

Table 1 summarises the re-processing that was done and the achieved results. First of all, it should be noted that the number of processed images are those that not only were successfully processed (i.e. the pipeline didn't exit with a fatal error, mainly because the algorithm failed to find correspondence between the input image and the baseline) but were also identified as having a good quality. The failure rate for CTX, THEMIS-VIS and MOC-NA images were 9.3%, 19.36% and 56.87%, respectively. The large MOC-NA failure rate can be explained by two main factors: the low quality of a large number of MOC-NA images (473/1558 of the input images are of very poor quality, if these are removed the failure rate drops to 37.49%) and the large resolution difference between MOC-NA and HRSC. More specifically, MOC-NA resolution can be as fine as 1.5 m/pixel, which is more than 8 times finer that the HRSC nominal resolution. The co-registration of images that have such large resolution differences from the baseline is inherently more challenging since imaging with a finer resolution reveals details that are not visible at coarse resolution, thus making it more difficult to find pixel-level correspondences between the input image and the baseline.

Instrument	# Images	# Processed	Accuracy X	Accuracy Y	Time (hours)
CTX	1,365	1,238	6.41 m	5.96 m	5.5
THEMIS-VIS	3,629	2,978	7.01 m	6.85 m	0.42
MOC-NA	1,558	672	5.05 m	4.77 m	0.49

Table 1. MC11-E processing using ACRO v1.0 within the iMars project.

The average accuracy (estimated by splitting the set of corresponding points into two halves, one used for co-registration and the second for estimating the residuals) of the successfully processed images is at the sub-pixel level, thus allowing pixel-based comparisons, which are crucial for the accurate automatic detection of changes. This accuracy was compared for a subset of 225 processed images (randomly selected) with their initial misalignment, in order to demonstrate the improvement that was achieved using the ACRO pipeline [1] (Table 2). It can be inferred that while originally the misalignment was very large (e.g. 43.5 CTX pixels) and pixel-level comparisons were not possible to use, with the use of ACRO this misalignment was improved by 30-50 times, reaching a sub-pixel level. We should note that the processed imagery is available through the iMars webGIS. Moreover, the processed CTX images were used to create a CTX MC11-E mosaic, which is also viewable through the iMars webGIS and the lack of any obvious "tears" in the mosaic testify to the pixel-level accuracy of the ACRO process.

Instrument	Misalignment Before ACRO	Misalignment After ACRO	IFoV in metres
CTX	261.14 m	8.2 m	6
THEMIS-VIS	617.83 m	12.47 m	18-35
MOC-NA	231.25 m	6.58 m	1.5-12

Table 2. Alignment improvement achieved with the original ACRO pipeline.

Finally, the average computational time (given in single-core hours) for all types of imagery is such that it allows the batch-mode processing of large amounts of data in a realistic timeframe (Figure 2). However, the processing of the complete Mars imagery using the available resources required further improvements on the computational complexity of the algorithm. This was the main motivation (apart from using the lessons learned from ACRO v1.0 to fix several minor issues of the implementation) for developing a second version of the algorithm, named ACRO v2.0.

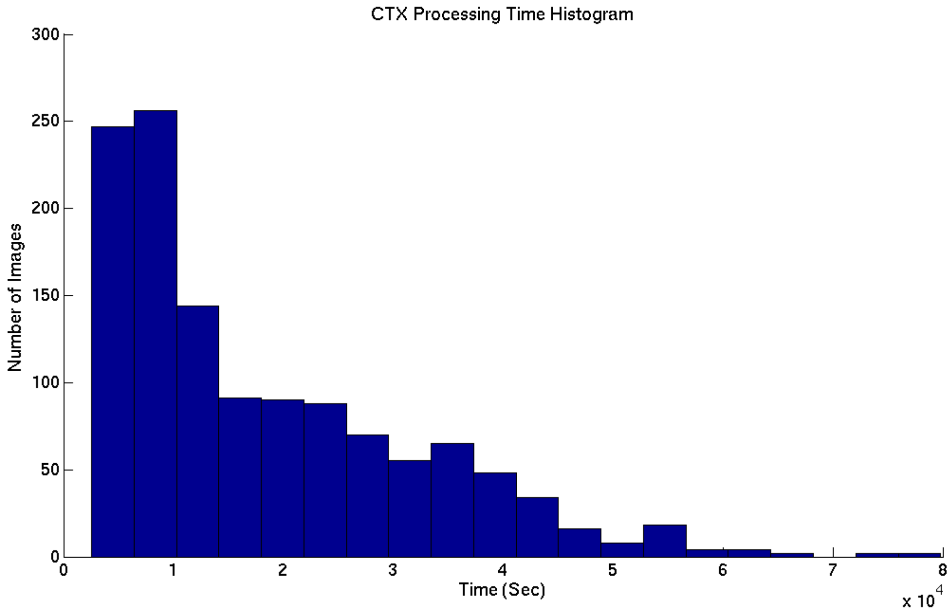

Figure 2. A histogram of the time (counted in seconds) that was required for the co-registration of CTX MC11-E products, in single-core threads on 2.3 GHz

2.2 ACRO v2.0

The second version of the ACRO pipeline used the lessons learned from the initial MC11-E processing as a starting point to further improve the co-registration and orthorectification pipeline.

The main differences between the two versions are:

- The replacement of the input image that is used for co-registration with a saturated duplicate (i.e. an image version in which the top and bottom 0.5% reflectance values are ignored. Note that this is the default processing in many planetary science software, including ISIS, in order to eliminate erroneous pixel entries). This is not suitable for dissemination (because the information in the pixels that are saturated is lost) but is more suitable for image matching, between the input image and the HRSC baseline because the image stretching sharpens image details which are necessary for the image matching module. In ACRO v2.0, the saturated version is used to estimate the georeferencing information of the input image, which is then used to co-register and orthorectify the original (non-saturated) image.
- The new design of the pipeline does away with any hard-coded parameters (including the projection and the central longitude), as well as a new implementation of the input image ingestion which allows a straightforward extension of the pipeline for new types of imagery. The latter is a positive

element of the project legacy, since the pipeline will require in the future only a few modifications to be able to co-register new Mars imagery which is not available during the iMars timeline (e.g. CaSSIS).

- Several minor improvements in the implementation of the algorithm that increased the computational time and reduced the memory allocation requirements.

ACRO v2.0 was initially used to co-register NASA images from the MC11-W half-quadrangle using the HRSC MC11-W mosaic that was provided to the CoI, Prof. J-P Muller, and was agreed to be used within iMars as a baseline. The statistics, shown in Table 3, indicates the improvement in all aspects that was achieved with the second version of the pipeline. Apart from the computational time, which was reduced by up to 35% (for THEMIS-VIS products), the failure rate has been reduced to 8.76%, 16.02% and 51.98% for CTX, THEMIS-VIS and MOC-NA respectively.

Instrument	# Images	# Processed	Accuracy X	Accuracy Y	Time (hours)
CTX	913	833	5.85 m	5.67 m	4.12
THEMIS-VIS	3,152	2,978	7.06 m	6.65 m	0.27
MOC-NA	1,220	586	4.82 m	4.68 m	0.4

Table 3. MC11-W processing using ACRO v2.0 within iMars project.

MC11-W products are also disseminated through the iMars WebGIS. Moreover, a mosaic of CTX MC11-W images is currently being processed and will be released in iMars WebGIS before the end of the project.

2.3 ACRO v2.1

One of the main obstacles in the co-registration of all high-resolution imagery of Mars is the fact that both the imagery datasets and the available baseline is not consistent, in terms of availability, quality, used projection, provided metadata, etc. As a result a number of variations of one core algorithm are needed for this task, each one focusing on a sub-set of the imagery. ACRO v2.0 implementation setup was developed with this rationale, and variations of the core algorithm were developed during the project.

The most important variation of the core algorithm was the pipeline used to co-register images that overlap with HRSC Level-4 products, but not with some of the sparse HRSC mosaics. Note that while the HRSC mosaics are well-suited for this task, they cover only 3.3% of the planet, while single-strip HRSC level-4 products cover almost half of Martian surface. As already stated, ACRO v2.1 uses sinusoidal (the “native” projection of the single strips) instead of equirectangular projection, while the baseline ingestion is faster than the one in ACRO v2.0. The pipeline was originally tested on NASA products overlapping with 34 HRSC single-strips, which were selected based on regions of interest, as determined from the Mars science literature. More specifically, 5 themes were used to select the 34 single-strips: (1) slope streaks [4], (2) active gullies [5], (3) Northern territories related to water ice [6], (4) regions near the South Pole (but not polar) and (5) randomly selected single-strips.

HRSC ID	Theme ID	Description	# CTX	# MOC-NA	# THEMIS-VIS
H1232_0000	1	Olympus Mons Aureole 1	1	25	22

H5247_0000	1	Olympus Mons Aureole 1	4	5	21
H5319_0009	1	Olympus Mons Aureole 2	2	30	69
H0049_0000	1	Olympus Mons Aureole 2	25	50	68
H2027_0000	1	Unnamed Slope Streaks	8	31	86
H1104_0000	1	Nicholson Crater	28	25	39
H2007_0000	1	Nicholson Crater	18	19	23
H2604_0000	2	Terra Sirrenum	116	133	210
H4355_0000	2	Terra Sirrenum	26	23	35
H2529_0000	2	Proctor-Matara Crater	60	119	120
H2496_0000	2	Proctor-Matara Crater	11	47	53
H2441_0000	2	Proctor-Matara Crater	81	139	89
H2158_0001	2	Promethei Terra	20	13	20
H0538_0000	2	Gorgonum	172	195	233
H5341_0000	3	Stokes Crater	14	10	20
H1485_0000	3	Northern Highlands	2	11	23
H5425_0009	3	Northern Highlands	21	11	24
H1276_0000	3	Milankovic Crater	9	19	39
H1465_0009	3	Kurowsky Crater	28	33	73
H2584_0000	4	Argyre Planitia	32	100	54
H2503_0000	4	Argyre Planitia	2	14	14
H2493_0000	4	Argyre Planitia	15	33	49
H2515_0000	4	Unnamed Near South Pole	7	86	55
H0416_0000	4	Unnamed Near South Pole	17	47	41
H1900_0000	5	Solis Planum	66	28	121
H4175_0000	5	Solis Planum	2	4	10
H4241_0000	5	Solis Planum	3	8	15
H2144_0000	5	Huygens Crater	6	14	32
H6441_0000	5	Huygens Crater	7	12	19
H2110_0000	5	Elysium Planitia	25	63	86
H2066_0001	5	Elysium Planitia	3	17	10
H1412_0001	5	Arcadia Planitia	47	79	142
H2286_0010	5	Cimmeria	10	15	15
H6476_0000	5	Cimmeria	34	45	76

Table 4. Single-strips processing using ACRO v2.1 within iMars project.

Table 4 shows the single-strips for which images are processed. The processing of this strips is not yet complete and its results will be reported in a future update of this report.

2.4 ACRO v2.2

Version v2.2 of the ACRO pipeline is a variation of v2.1 which is tailored to products of the polar regions of Mars, i.e. uses polar stereographic projection as the default projection of the pipeline. ACRO v2.2 is used to process images from the South Polar Residual Cap using HRSC level-4 single strip DTMs and ORIs that was produced by a UCL pipeline (see D4.1). The processing is an ongoing work and is going to be reported in a future update of this report. An example of two CTX images co-registered to HRSC SPRC baseline is shown in Figure 2.

Figure 3. A mosaic of 2 CTX images and an HRSC ORI. The CTX images were co-registered to the HRSC ORI using ACRO v2.2. The yellow-coloured image in the top-left part of the figure is CTX image D14_032511_0959_XI_84S078W_ORI (Ls 345) while the blue-coloured image in the centre is the CTX image B11_013813_0955_XN_84S078W (Ls 299). The background image is the level-4 HRSC ORI H2288_0000 (Ls 312). All images are demonstrated using polar stereographic projection.

2.5 ACRO v2.3

Version ACRO v2.0 can be adjusted so as to use a different input than the HRSC baseline. This has be done in ACRO v2.3, so as to re-process imagery that failed to be co-registered using the HRSC baseline due to multi-instrument differences in the resolution, the point-spread function and the imaging setup. In ACRO v2.3 an image of the same instrument that has been successfully co-registered is used as a baseline to co-register images of the same instrument. Specifically for MOC-NA, because their coverage is rather sparse, if a co-registered MOC-NA is not available then CTX is used as a baseline instead.

The re-processing started with the failed products of MC11-E, i.e. 127 CTX, 651 THEMIS-VIS and 886 MOC-NA images. From them, 103/127 CTX images could be co-registered using CTX as a baseline, 622/651 THEMIS-VIS could be co-registered using THEMIS-VIS as a baseline and 820/886 MOC-NA images could be co-registered using either MOC-NA or CTX as a baseline. The processing reduced CTX failure rate from 9.3% to 4.54%, the THEMIS-VIS failure rate from 19.36% to 8.42% and MOC-NA failure rate from 56.87% to 33.06%. Statistics about the accuracy, as well as the results of the re-processing of MC11-W and single-strips failed imagery will be given in a future update of this report.

3. Conclusions

Task 4.4 of WP4 is about the co-registration of NASA imagery to the HRSC baseline, a task that demands not only the development of a core efficient algorithm that can achieve a fast and reliable co-registration of high-resolution multi-instrument planetary images to a common baseline but also a number of variations that overcome the apparently random and incomplete nature of the current high-resolution Mars imagery. These variations were a task that required substantial human resources to be developed. This created a bottleneck in the processing of the global imagery, which while being under way is not expected to be completed before the end of the project. However, a substantial number of images will be processed, and the pipelines for extending this to the rest of Mars orbital imagery are just a matter of computer and human resources, especially since the developed algorithm is fully automatic and require minimum human resources. Note that UCL has already secured 20,000 core hours of funding from Microsoft Azure® which may be used to process the rest of Mars orbital high-resolution imagery, before January 2018.

Moreover, even though the developed algorithm achieved state-of-the-art resilience to resolution differences between the input image and the baseline, there is a limit on the resolution differences for co-registration in order for it to have any practical meaning. For example, a HiRISE image has a resolution of 25cm/pixel, which is 50 times finer than HRSC resolution. This means that a 50x50 HiRISE patch corresponds to a single HRSC pixel. The matching of images with such large resolution difference would be possible if (according to Shannon’s sampling theorem) the spatial frequency of the terrain is such that the sampling difference wouldn’t change the signal (i.e. the image). In practical terms, this would mean features of size no less than 25 metres (since 12.5 m/pixel is HRSC resolution). On Mars, the surface is very rarely so “simple”, since high-resolution imagery both from orbit and from rovers have revealed features of great detail, on scales of centimetres or even millimetres. Under this circumstances, co-registration of images with so much resolution difference is a very challenging task, especially when following the design principle to build a fully automatic pipeline that can process large volumes of data without requiring any parameter tuning. The systematic, batch-mode, co-registration of products with such high-resolution should wait for a 3D baseline of higher resolution (between HiRISE and HRSC), before they can be added to the dataset of Mars geometrical aligned image dataset.

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