SOME ASPECTS OF MODERN PHOTOGRAMMETRIC IMAGE PROCESSING OF SOVIET LUNOKHOD PANORAMAS AND THEIR IMPLEMENATION FOR NEW STUDIES OF LUNAR SURFACE

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ABSTRACT:

Recently the Lunar Reconnaissance Orbiter (LRO) has obtained images in unprecedented detail (up to 0.3 m/pixel) which cover landing sites from previous missions to the Moon. These new data allow us to carry out studies of Lunokhod landing sites in more details combining orbital high resolution images with surface panoramas taken by the rovers in-situ during the Lunokhod missions. However, methods of panorama image processing have changed significantly since then and a lot of supplementary information was lost. So we have developed new technology of Lunokhod panorama processing by means of modern photogrammetric software and recovering lost exterior orientation parameters of panoramas using LRO data and specially developed programs.

1. INTRODUCTION

Russia has a long tradition in Lunar exploration. Early highlights of Lunar exploration include the first exploration the Lunar far side. Russian spacecraft also performed the first soft landings. Also, the historic Lunokhods were the first planetary rovers, extremely successful in their early missions. Lunokhod-2 has completed a traverse of more than 40 km.

Recently the Lunar Reconnaissance Orbiter (LRO) has obtained images in unprecedented detail (up to 0.3 m/pixel) that cover the all Moon landing sites from previous American and Soviet missions. Also, stereo images have been obtained by LRO Narrow Angle Camera (LRO NAC), which used for photogrammetry image processing, including Digital Elevation Models (DEMs) and orthomosaics. The Lunokhods landing molule including their wheel tracks can be seen at the LRO NAC orthoimages.

MIIGAiK takes part in PRoViDE (Planetary Robotics Vision Data Exploitation) project which aims to assemble a major portion of the imaging data gathered from different vehicles and probes on planetary surfaces into a unique database, bringing them into a spatial context and providing access to a complete set of 3D vision products (http://www.provide-space.eu/). So in this study we aim to process Lunokhod panoramas with modern photogrammetric techniques.

2. METHODOLOGY

2.1 Available data and software

MIIGAiK has recently obtained archive panoramas from the State Archive of Russian Federation for research purposes, including those from the missions Luna 9, 13, 17, 20, 21. Three of them (Luna 9, 13 and 20) were stationary lander missions, where only a few panoramas were taken from the landing site. The other two missions (Luna 17, 21) had rovers – Lunokhod-1 and Lunokhod-2, respectively. Panoramas taken by the rovers over their wide activity area are highly useful for geomorphologic and other analyses of the different types of lunar surfaces.

For photogrammetric processing commercial photogrammetric software PHOTOMOD (Racurs™) is used (http://www.racurs.ru/?lng=en&page=634). For transformation and projecting of assembled panoramas special software was developed.

2.2 Description of Lunokhod's cameras

Each Lunokhod had two panoramic cameras on each side (one horizontal and one vertical). Horizontal cameras obtained near-horizontal views, the width of panorama is 30° (500 samples) and length is a bit more than 180° (3000 lines). Optical axes of horizontal cameras were diverted from the horizon by 15^0 downwards (Fig. 1). Horizontal panoramas are the main source of information for analyzing the structure of the lunar regolith and relief and making topographic survey. A stereo-photogrammetric survey of the surrounding area was usually held by means of taking panoramas from two positions of the Lunokhod (Vinogradov, 1971). Vertical cameras have field of view $30^0 \times 360^0$ and can capture the sky, the Earth and the Sun, Lunokhod wheels, antennas, and a special device used as an indicator of gravity direction (vertical line or Lunokhod tilt).

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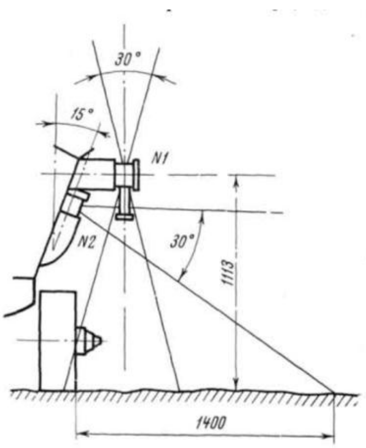

Fig. 1. Scheme of field of view of vertical (N1) and horizontal (N2) panoramic cameras (Vinogradov, 1971)

Panoramic sweeps of the surroundings in these cameras were made with the help of a scanning mirror, which performed oscillatory and rotating motion. So panoramic image represents a part of sphere (spherical projection - see Fig. 2). It's a non-standard model for modern software and in order to use panoramas for stereo photogrammetric processing they have to be transformed into central projection.

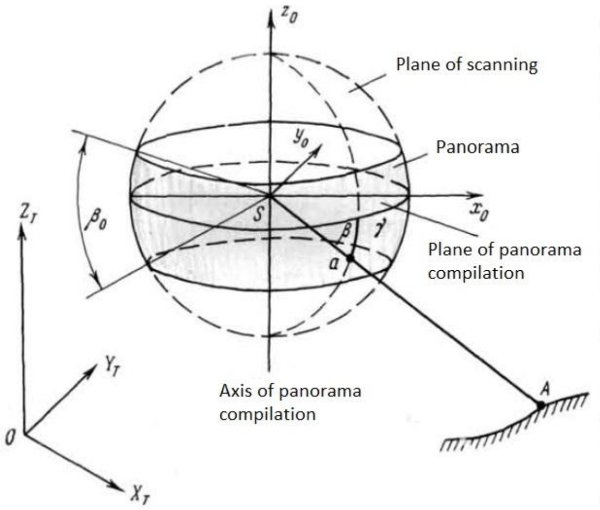

Fig. 2. Scheme of construction of panoramic images (Vinogradov, 1971)

2.3 Preparation of panoramas

The objectives of our work are to fully exploit the historic Lunokhod data based on LRO NAC photogrammetry image processing and use the results for landing site selection for future lunar missions. Unfortunately, many of the relevant operational parameters of the Lunokhods mission are lost. The images are noisy, and image dynamics is low. Timing and positional information, as well as the geometric properties of the cameras are not known and must be determined in the process.
We have developed an algorithm for reconstruction of unknown exterior orientation and processing of panoramas that allowed us to search for stereo pairs and obtain a stereo model from panoramas (where possible).

First of all, we need to assemble panoramas as we obtained them from Russian State Archive in form of scanned fragments. Then we resample them close to their original size (scanned panoramas have the size 5 times larger than real ones). Assembled panoramas are still in spherical projection.
Besides that there are some distortions caused by non-uniform rotation of the scanning mirror (marked with red arrows in Fig. 3).

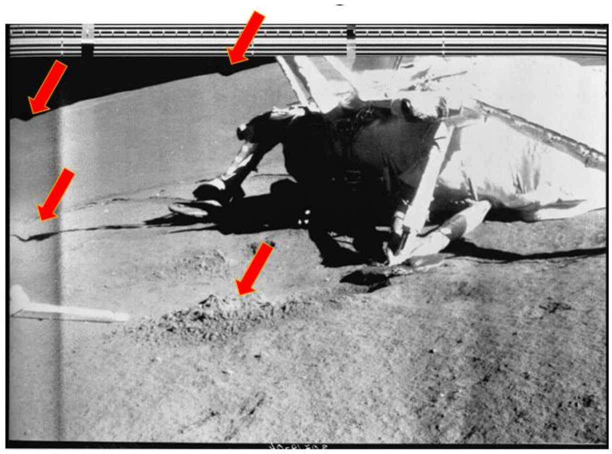

Fig. 3. Image distortions caused by non-uniform rotation of the scanning mirror

2.4 LRO NAC image processing

We have created a detailed DEM with a grid size of 1 m from stereo photogrammetric processing of two LRO NAC stereopairs (M150756018 and M150749234 (left and right images)) (Zubarev et al., 2012; Zubarev et al., 2013). The DEM covers the whole area of Lunokhod-1 track. We have also selected and orthorectified (using the created DEM) LRO NAC images with the best resolution and illumination conditions for this region. These products (as well as DEM and orthomosaic obtained by our colleagues at DLR) were used to carry out studies of Lunokhod-1 traverse and morphologic assessments of the working area (Karachevtseva et al., 2013).

We have also created DEM for Lunokhod-2 working area but its resolution is worse than for the Lunokhod-1 area. It is so because Lunokhod-2 route is more than 4 times longer and is elongated from West to East so to cover it all several NAC stereopairs are needed. Also conditions of these stereo images are not as good as for the first Lunokhod: resolution, stereo angle and relative accuracy of the spacecraft coordinates are worse. The work on improvement of the Lunokhod-2 DEM is in progress.

3. DETERMINATION OF EXTERIOR ORIENTATION OF PANORAMIC IMAGES

3.1 The problem of unknown parameters

Further processing of panoramas is complicated by lack of some camera parameters and their calibration (principal point, distortion, other parameters, e.g. focal length and image size, not defined precisely), exterior orientation parameters (coordinates of observation points; Lunokhod orientation – azimuth and tilts), parameters of digitizing.

So for panoramic image processing we have to use nominal interior orientation parameters of the cameras published in (Vinogradov, 1971) or some best fit parameters determined iteratively.

In order to determine exterior orientation of the panoramas we have developed two different ways.

3.2 The first way of determination of exterior orientation

We have developed a special program which allows us to bring assembled panoramas (Fig. 4a) in spherical projection to the horizon, in other words, to determine tilts of the camera while shooting (Fig. 4b). Determination of the tilts is an iterative process.
Another module of the program can transform the panorama from spherical into central projection using the determined tilts (Fig. 4c). Stereo pairs of panoramic images in central projection may be used for stereo photogrammetric processing and creation of DEM of the lunar surface.

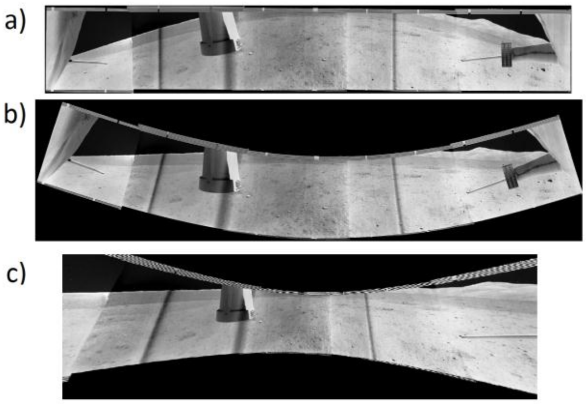

Fig. 4. Lunokhod-2 panorama a) assembled from archive fragments (spherical projection); b) assembled and brought to the horizon (spherical projection) with the following tilts of the panorama: cross tilt – 17.0° (downwards the surface), longitudinal tilt – 2.0°; c) assembled, brought to the horizon, and transformed into central projection (same tilts).

Then, in another module of this program it is possible to create orthoimage from the panorama (Fig. 5). The geometric quality of orthoimage also works as a control of determined tilts: visible track and craters should be geometrically correct. However, sometimes local relief affects the resulted image significantly.

Fig. 5. A part of orthorectified panoramic image obtained by Lunokhod-2.

Last step in this way is to pinpoint the observation sites on orthorectified LRO NAC images – to fit orthorectified panoramas to the LRO NAC orthoimage manually. Any information on Lunokhod position or exact observation time could be very helpful. But for the most of panoramic images we know only lunar day of shooting. And during one lunar day (14 Earth days) Lunokhod-2 could cover the distance up to 10 km. Moreover, practically everything what is seen on panoramas is too small to be identified on LRO images (which resolution is 0.3-0.5 m/pixel while we can see details up to several cm in the foreground of panoramas).

3.3 The second way of determination of exterior orientation

The second way to determine exterior orientation is to model panoramas for several possible observation points (based on the LRO NAC DEM and orthomosaic and using possible tilts) and then compare the artificially modelled panorama (Fig. 6) with the assembled one (Fig. 7). If they seem to be identical (after several iterations) we bind used exterior orientation parameters to the assembled panorama.

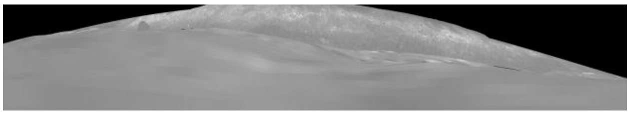

Fig. 6. Panoramic image modeled at MExLab using LRO NAC orthoimage and DEM

Fig. 7. Assembled archive panorama for approximately same region as modeled panorama in Fig. 6.

4. CONCLUSIONS

We have developed possibilities to study historic lunar panoramic images in combination with high-resolution LRO data. We derived terrain models and orthoimages of the sites for data fusion with the panoramic images obtained in-situ from the lunar surface. The fully reconstructed panoramas obtained by new photogrammetric processing techniques (Mitrokhina et al., 2013) provide morphology and morphometry information which can be used for quantitative surface analyses of Lunokhod regions and extrapolating assessment of lunar polar area. They can be used for detailed mapping, calculation and morphologic description of stones and small craters, determination of physical parameters of lunar regolith based on the depth of Lunokhod traverse.
Where stereo images are available, we will produce topographic models by photogrammetric processing. Processed panoramas contain a lot of geomorphologic information. After all panoramas are processed and identified it will be possible to continue the study (Karachevtseva et al., 2013) of Lunokhod area in more detail.
Results of our work, including rebuilt archival panoramas, will be placed into a MIIGAiK planetary database and will be available via Geo-portal (http://cartsrv.mexlab.ru/geoportal/).

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