AUTOMATED DTM GENERATION FOR LOW TEXTURED IMAGES USING MULTIPLE PRIMITIVE MULTI-IMAGE MATCHING (MPM)

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ABSTRACT:

In the frame of our long term, interdisciplinary Nasca/Palpa project, conducted in a close cooperation between our group and archaeologists from the German Archaeological Institute (DAI, KAAK Bonn), our aim is to develop a GIS database well-suited for management and analysis of the archaeological and spatial data acquired during various field campaigns by the project partners. The region around the two localities of Nasca and Palpa, about 400 km southeast of Lima (Peru), is well-known for its famous geoglyphs, ground drawings which were carved into the desert sand during the Nasca culture period (200 B.C. – 650 AD), the so-called "Nasca lines". In order to map the geoglyphs and derive preferably accurate Digital Terrain Models (DTM) and orthoimages suited for documentation, digital preservation and GIS-based analyses, three blocks of aerial images were acquired: Sacramento (211 images, B/W and Color) and San Ignacio (168 images, B/W) around Palpa and the Nasca block (401 images, B/W) covering the *Pampa de Nasca*. The actual photogrammetric work focuses on the Nasca block, aiming for a widely automated processing concerning aerial triangulation and DTM generation. Previous investigations have shown that commercial photogrammetric software systems were not suited for an accurate DTM generation, mostly due to the xeric characteristic of the landscape which leads to low texture and partly poor image quality. In order to overcome the shortcomings of commercial software available today, our inhouse software SAT-PP (Satellite Imagery Precision Processing) was used for DTM generation. SAT-PP, contrary to most commercial systems, applies a simultaneous, multiple primitive multi-image matching approach for point measurement. Therefore, an increased accuracy and reliability of the matched points can be expected. A comparison of the DTMs generated for several stereo models versus the results obtained by commercial systems as well as to manual measurements performed on an analytical plotter shows the high accuracy potential of the SAT-PP approach.

1. INTRODUCTION

1.1 Area of investigation

Situated about 450km southeast of Lima, Peru, near the modern city of Nasca in the department of Ica, the *Pampa de Nasca,* well-known for its geoglyphs, the so-called "Nasca lines", is an arid desert plateau with an extent of about 400km^2. The *Pampa* itself is a flat plane, slightly ascending towards north-west direction, nerved by dry water channels, the *quebradas,* formed by Andean melt waters which temporarily flow about 50km to the south towards the Pacific Ocean. In close cooperation with archaeologists from the German Archaeological Institute, Commission for Outer European Cultures (DAI, KAAK Bonn), the aim of our Nasca/Palpa project is a complete 3D mapping of the ground drawings carved into the desert sand during the Nasca Culture period from 200 BC to 650 AD in order to digitally preserve these unique remains and to integrate them into the Nasca-GIS, which has been developed during earlier stages of the project (Lambers, 2006), containing nowadays a large part of the geoglyphs located around the town of Palpa, ca. 20 km north of the *Pampa de Nasca*. The mapping of the Nasca geoglyphs will start as soon as a final DTM and high resolution orthoimage for the region will be available.

1.2 Data acquisition

In 1997 and 1998, two photoflights, sponsored by the SLSA (Swiss-Lichtenstein Foundation for Archaeological Research Abroad), were conducted for the acquisition of suitable aerial images at a scale of about 1:10,000 for the Nasca area and at about 1:7.000 for Palpa (Sacramento and San Ignacio).

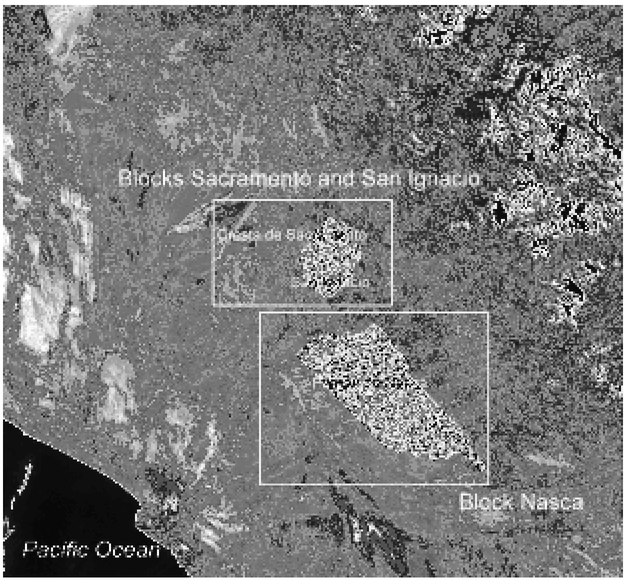

Figure 1: Overview of the Nasca/Palpa region showing the 3 acquired aerial image blocks

While the first series of coloured aerial images, taken in 1997, showed poor quality, during a second flight in 1998 an amount of 401 B/W images was acquired, covering the whole *Pampa de Nasca.* The block consists of 14 stripes of varying number of images (Fig. 1). During the flight, approximate coordinates of the projective centres were measured using kinematic GPS and stored for each image. The images show an overlap across and along flight direction of about 60%, enabling stereoscopic coverage of the whole area. The aerial images were scanned at a resolution of 15µm with a photogrammetric scanner Vexcel Ultra Scan 5000. Furthermore, signalised control points were determined using DGPS (Gruen & Brossard, 1998) during a field campaign in 1998, additional natural control points were determined during a field campaign in 2003 (Fig.). While the first campaign used two reference stations, one at Nasca airport and one generated in the centre of our area of investigation, for the second we determined a reference station near Palpa. For identical points determined from all three reference stations, a mean error of 3cm was obtained from the processing of the GPS measurements, according to 0.2 pixels. For all ground control points, an accuracy of 10cm therefore can be assumed for all points in the worst case, when considering the relative low accuracy of the natural GCPs. The ground control points were transformed to the UTM projection, Zone 18S, with the WGS 84 ellipsoid as vertical datum, corresponding to the standard projection and datum of the peruvian topographic maps and all other spatially related project data.

1.3 Image orientation

While the first two blocks, Sacramento and San Ignacio, were processed manually on an analytical plotter (Sauerbier & Lambers, 2003), which turned out to be a very time consuming approach, for the Nasca block we aimed for a widely automated photogrammetric processing. The block design is a traditional stripe design with parallel stripes exclusively (Fig. 2).

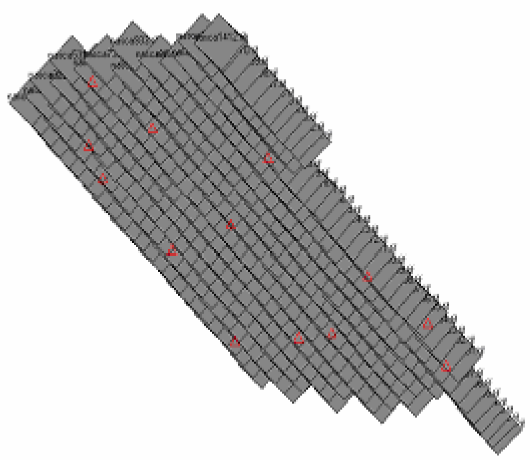

Figure 2: The design of the Nasca block

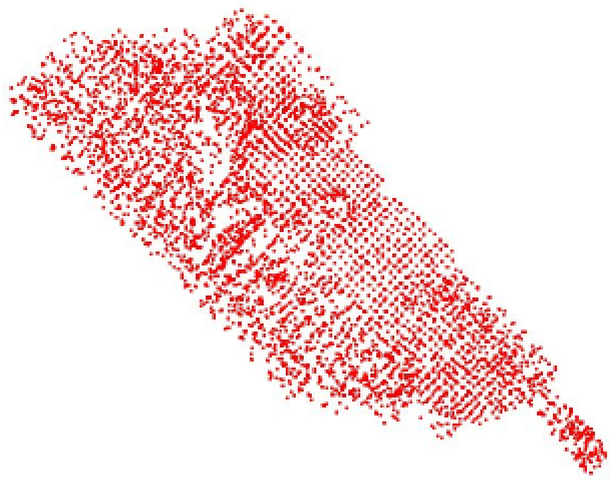

Figure 3: Tie point distribution as resulting from LPS Core point measurement

Various tests using different commercial software systems showed, that sufficient results could not be yielded in a fully automated mode. Especially the low texture in most of the images and partly poor image quality resulted in areas where no reliable tie points were measured, additionally, the high overlap of the images was not exploited optimally by the automatic measurements. Nevertheless, image orientation was performed using the photogrammetric software Leica Photogrammetry Suite (LPS Core) version 8.7. After project setup and automatic interior orientation for all images, the recorded coordinates of the projective centers were introduced as approximative values. Additionally, the flight direction was known approximately, therefore an initial orientation existed which allowed us to directly start with automated tie point measurements without a need for initial manual measurements. For the whole block, a total of 6699 points were measured automatically and the 13 control points were measured manually in the images. Successful matching could not be performed in all subregions of the block, especially in the center, where low image texture and poor image quality occurred, only few points were generated. Nonetheless, the point density was sufficient. Subsequently, bundle block adjustment was started in LPS Core, but did not succeed due to a large amount of blunders which could not be identified and removed by the software. Therefore, the GCPs, image measurements and camera information were transferred to ORIMA (L. Hinsken for Leica), which provides more detailed error analysis and editing tools. Moreover, the bundle adjustment is more flexible concerning the consideration of different additional parameters and user-defined settings. In ORIMA, bundle adjustment finally could be solved with a resulting s_0 = 6.4µm, which is the global accuracy of the image measurements, roughly according to a third of a pixel. The RMSE values for the control points of 0.058m and 0.057m for X and Y direction, respectively, and 0.118m in Z direction show that the absolute orientation of the Nasca block also could be performed at a reasonably good accuracy. The blunder detection algorithm in combination with the adjustment eliminated 1030 image points, according to a 15.4% rate of blunders. Another important fact is the poor exploitation of image overlap (Tab. 1), 45.84% of the points were only measured in two images whereas the stereo overlap would enable a higher number of rays per tie point.

Table 1: Exploitation of image overlap by automated tie point measurement using LPS

Number of rays	Number of points	Percent
2	3071	45.84%
3	1522	22.72%
4	1174	17.53%
5	680	10.15%
6	199	2.97%
7	41	0.61%
8	10	0,15%
9	2	0,03%

2. DTM GENERATION

Fully automated DTM and DSM generation from aerial imagery at high accuracy is still an unresolved issue in photogrammetry. Although a wide variety of photogrammetric software providing tools for automatic point measurement are on the market, no system is known yet which produces reliable results for each type of images and image content. Factors with influence on the accuracy of image matching have been mentioned in the literature (Gruen et al., 2000; Zhang, 2005), nevertheless a decisive progress is not observable regarding the commercially available software packages.

2.1 Investigations on DTM generation for Nasca imagery

Accuracy tests concerning the Nasca imagery were performed using commercially available photogrammetric software (Sauerbier 2004), e.g. with Z/I Image Station (Intergraph), Virtuozo versions 3.3 and 3.1(Supresoft Inc.). Comparisons were conducted between the automatically generated grids and grids derived from the manual measurements. All compared grids had a mesh size of 5m, the same applies to the datasets used for the work presented in this paper. The results showed that none of the investigated systems yielded satisfactory results besides the raw matched points produced by the Z/I Image Station software. The reasons for failure vary between the three products. While the interpolation module implemented in Z/I Image Station produced an extremely smoothed surface, both Virtuozo versions produced relatively high standard deviations up to 3m identified through comparison of the resulting grid with a DTM derived from manual measurements on an analytical plotter. Moreover, an effect valid for all investigated systems occurred for steep slopes, showing gross height errors of several meters due to the different perspective that slopes appear in neighbouring images. Concluding the investigations performed with the mentioned commercial software systems, one can state that concerning both accuracy and reliability of matched points especially in the case of steep slopes and lowly textured planes, an investigation of a simultaneous multi-image matching approach would be worthwhile. Therefore, it was decided to process the Nasca block using our inhouse developed software SAT-PP. In contradiction to the mentioned software packages, instead of pairwise matching, SAT-PP uses all available images which cover an area of interest (Zhang & Gruen, 2004). Additionally, it makes use of a coarse-to-fine hierarchical matching process, trying to extract and match grid points, feature points and edges.

The workflow for DSM generation in SAT-PP (Fig. 3) still requires a certain amount of manual interaction and measurement. Given that imported and oriented images are at hand, one first has to generate epipolar images for stereo viewing. It has to be mentioned here, that during image import the Wallis filter is applied in order to enhance image contrast locally in the images. In the next step, it is recommended to measure seed points manually, at least 5, depending on image quality, texture and topography the number has to be increased. Furthermore, a mask has to be defined which determines the area inside the stereo model for which the DSM will be generated. Although the software offers the option to generate the mask automatically, first tests have shown that a manual definition should be preferred in order to avoid that fiducial marks and the image frame cause problems during the matching procedure. After seed point measurement and mask definition, image matching can be started. Until now, there is no option that would allow to influence matching parameters besides the choice of the mesh size of the resulting DSM.

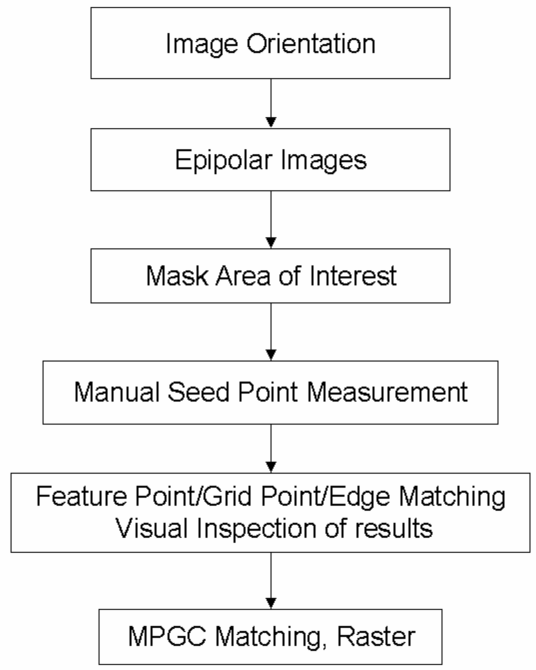

Figure 3: Workflow for DSM generation in SAT-PP

2.2 Results

DSMs for the comparison were determined using SAT-PP for the areas of 5 stereo models with a mesh size of 5m. The comparison of the DSMs achieved by SAT-PP and the DTMs derived from manual analytical plotter measurements was performed in Geomagic Studio version 6 as a 3D comparison of a reference surface (manual measured DTM) with the DSM points derived from SAT-PP along the surface normals, according to the euclidean distance between both datasets. The automatically derived DSMs were not edited, therefore this comparison displays the quality of the implemented algorithm as well as of the applied interpolation method. In this case, the direct comparison of DSM and DTM is valid due to the xeric characteristics of the landscape and the resulting lack of vegetation. This has been evaluated in a diploma thesis (Keller, 2003), where no significant difference between DTM and DSM could be observed. DSMs were determined covering the area of 5 stereo models, 2 of them single models and 3 neighbouring models which were processed together in order to achieve multi-image coverage and to enable multi-image matching. For the 2 single model areas, additionally the neighbouring images were included for the same purpose. The results of the comparison (Table 2) show that the RMSE value is generally smaller for SAT-PP than for the results obtained by the other systems (Sauerbier, 2004).

Table 2: Results of the comparison between SAT-PP generated DSMs and reference DTM measured on an analytical plotter WILD S9

Model	1	2	3	4	5
Maximal positive Deviation [m]	10.44	39.64	9.13	5.01	6.22
Maximal negative Deviation [m]	-8.31	-44.61	-11.67	-5.00	-9.79
Average positive Deviation [m]	0.77	0.67	1.19	0.002	0.71
Average negative Deviation [m]	-0.63	-0.83	-1.79	-3.82	-0.74
Average Euclidean Distance [m]	0.003	0.004	-0.49	0.001	0.015
RMSE [m]	0.97	1.20	2.00	0.11	0.98

Additionally, the range between the minimum and maximum deviation between test and reference data is significantly lower for the SAT-PP DSMs compared to earlier tests (Sauerbier, 2004) and a systematic bias in height could not be observed in most of the investigated stereo models (Table 2). Regarding the number of matched points, due to the low contrast image content, only few feature points could be extracted and matched successfully. The same applies to the detected edges, furthermore, the effect of low texture is also visible for the grid point matching procedure as the quality indication shows a large amount of yellow and red marked points, which are critical, in comparison to the amount of green coloured points that can be assumed to be reliably matched. The same effect concerning the pure number of matched points could be observed during investigations on the originally matched points generated using Z/I Image Station and LPS. Nevertheless, the interpolated raster generated using SAT-PP displays the topography much more detailed than the results obtained by commercial systems (Sauerbier, 2004) and manual measurements (Fig. 4 and 5), especially in the plane areas. The effect visible near the upper border of Model No. 1 occurs in areas of overlapping stereo models and will have to be investigated in future work. Moreover, the feature point density as well as the density of the matched edges is low. The extracted lines mostly do not coincide with breaklines a human operator would measure, e.g. mountain ridges. SAT-PP allows the user to view the matched points and edges in stereo mode overlaid on the images, therefore it is possible to check the results from matching visually on mismatches.

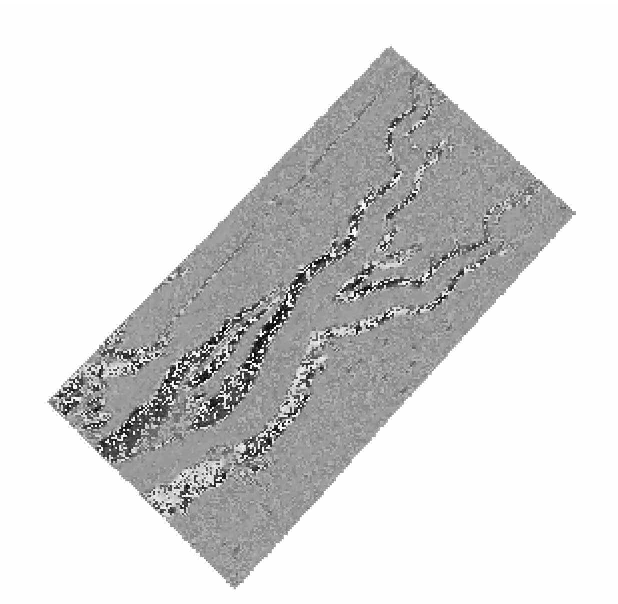

Figure 4: Hillshade view on Model No. 1 generated with SAT-PP

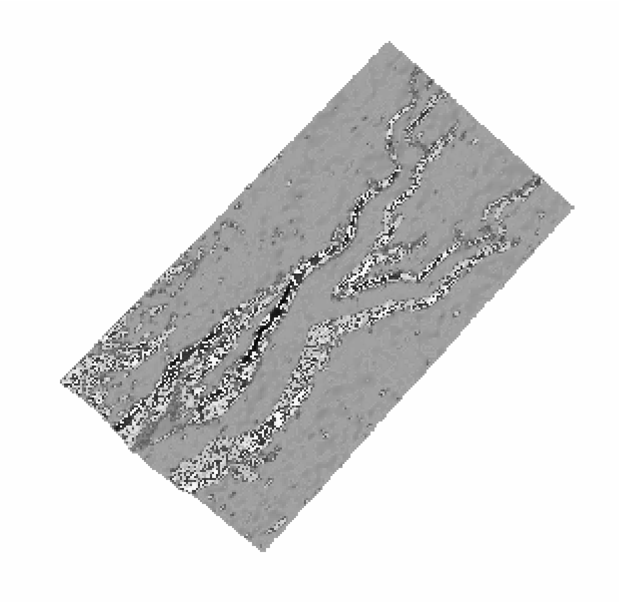

Figure 5: Hillshade view on Model No. 1 produced manually on an analytical plotter WILD S9

Another means to evaluate DTM/DSM data were the derived contour lines, which allowed for a visual inspection of the morphological correctness of the generated models and approve the impression given by the hillshade views. Due to the high point density, mainly from grid point matching, the surface is modeled more detailed than the manual measured DTM which has a lower point density in plane areas and therefore does not consider topographic elements smaller than the point distance. According to the investigations performed for the commercial systems, the SAT-PP DSM shows the largest deviations between reference and test dataset at the steep slopes (Fig. 6), although the maximal values are lower (Sauerbier, 2004). Again, the step effect at the border to the neighbouring stereo model is recognisable, although it is in a range of below 1m difference. This effect was observable in most of the DSMs generated in multi-image mode, in stripe direction as well as between stripes, and may be caused by the matching mask, in future work we will vary this parameter in order to resolve the problem. Deformations of stereo models could be another reason, due to the relative low number of control points compared to the size of the covered area. In contrast to this, it must be stated that the effect did not occur e.g. in LPS, using identical image orientation parameters.

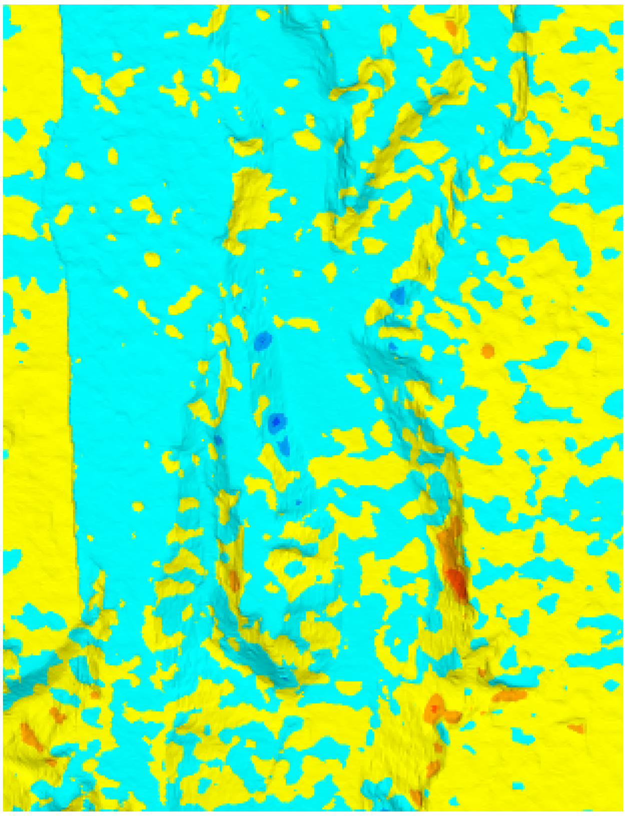

Figure 6: Differences between manual measurements and SAT-PP results for Model No. 1. (Large differences are dark, small differences light)

3. CONCLUSIONS

The first investigations using SAT-PP for the Nasca images have shown, that improved results can be achieved with the multiple primitive multi-image matching approach. Although still full automation is not achieved, the results are within the range of commercial systems, mostly even better. This does not result from the multi-image part of the approach, which showed problems in overlap areas between stereo models, but from the multiple primitive approach. Whereas feature point and edge matching exploit the significant features in the image content, the grid point matching allows for a very high point density and achieves reasonable result in low textured areas (Gruen & Zhang, 2002). Even though the quality of every single grid point can not be assessed exactly without reference data of a higher degree of accuracy, the surface covered by all investigated stereo models was modeled at higher detail than with the commercial systems.
In future work, the effect at the borders between stereo models will be further investigated, which then will show if multi-image matching will increase the accuracy for this set of images significantly, especially in slope areas.

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