Accuracy of automated aerotriangulation and DTM generation for low textured imagery

Report

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ACCURACY OF AUTOMATED AEROTRIANGULATION AND DTM GENERATION FOR LOW TEXTURED IMAGERY

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ABSTRACT:

The Nasca-Project at ETH Zurich aims for a GIS-based analysis of the topography and the geoglyphs carved into the ground by the ancient Nasca (200 B.C. – 600 A.C.) in the desert region of Nasca/Palpa, about 500 km south-east of Lima, Peru. In 1998, three blocks of aerial images have been acquired during a photoflight. Two of these blocks (about 400 images, scale 1:7.500) were processed using an analytical plotter Wild S9 during 4 years of manual measurements, resulting in a high resolution DTM and 3D-vectors of the geoglyphs as well as topographic elements (rivers, streets, houses). Especially aerotriangulation and DTM-measurements have been time-consuming processes. For the third block of Nasca imagery (about 400 images at a scale of approximately 1:9100) we aim for an automated processing (Aerotriangulation and DTM generation) to provide accurate data as a basis for terrain analysis (visibility studies, surface calculation etc.) in relation to the geoglyphs (Grün et al., 2003).
Actual digital photogrammetric stations (DIPS) are examined for this case of low textured imagery due to the desertous characteristic of the landscape. Aerial triangulation and DTMs generated using Z/I's Image Station™ modules ISDM and ISAE, version 4.00, and Supresoft Inc. Virtuozo™ versions 3.1 and 3.3 are compared to reference data measured on an analytical plotter Wild S9. The main focus of this paper is on DTM generation, as for aerial triangulation no strictly comparable results, produced fully automatically, could have been achieved.

1. INTRODUCTION

One of the most important limiting factors concerning automated aerotriangulation and DTM calculation is texture. Actual digital photogrammetric stations allow for good results in most cases if the processed imagery contains texture with high contrast. Problems occur processing images which cover low textured areas, e.g. forests, glaciers, grasslands or deserts. Especially in these areas, matching algorithms fail measuring identical points in two or more images which leads to blunders or even non-measured points. The consequences during aerotriangulation can be instable relative orientations of images if there are not enough points to achieve a regular distribution, and therefore a decreased accuracy of the absolute orientation. DTM generation is affected by blunders or even gaps in areas where matching is impossible (Baltsavias et al., 1996). Both cases require costly manual editing or measurement. The data used for the examination of aerotriangulation consists of a subblock of 26 aerial images (B/W) of the Pampa de Nasca which were triangulated on an analytical plotter Wild S9, using IGP's bundle adjustment software BUN and on Virtuozo 3.1 during a diploma thesis (Keller, 2003). These images were then also processed on Z/I's Image Station. To compare DTM generation, one stereo model of this subblock and 4 stereo models of another subblock were used. For both aerotriangulation and DTM generation the results of the automated processing were compared, no manual measurements or editing were applied. The area covered by the generated DTMs does not contain vegetation or buildings, thus the DSMs calculated by the DIPS can be considered as DTMs.
The used images were scanned at a resolution of 15 microns according to 13.65 centimetres in object space. The overlapping along strip as well as perpendicular to the flight direction is 60%. See figure 1 for an example of the used images and their content.
The landscape covered by the images is mostly flat, here and there interrupted by quebradas, usually dry valleys formed by draining water from the Andes. The surface consists of little stones and sand.
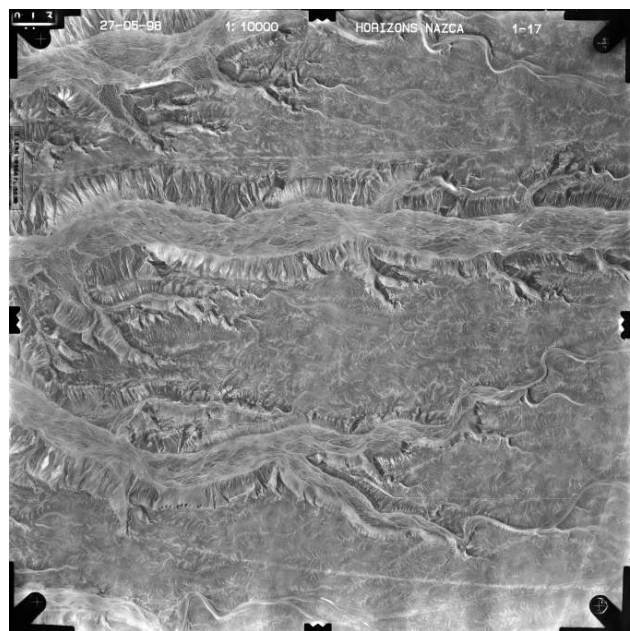

Figure 1: Typical aerial image (117) of the Pampa de Nasca

2. AEROTRIANGULATION

2.1 Test data

To achieve reliable conclusions, high accuracy reference data is required. For one area of investigation, a triangulation was measured on an analytical plotter Wild S9 using 26 aerial images from 8 different strips. The acquired image coordinates of the control and tie points, measured according to the von Gruber distribution, then served as input data for the bundle adjustment package BUN. As a result, a σ_0 of 9.65 microns could be achieved for the processed subblock as global accuracy. Compared to the values we achieved for the two blocks of Palpa imagery (scale 1:7500), $\sigma_0 = 13.3$ microns and $\sigma_0 = 9.5$ microns, the global accuracy of 9.65 microns can be considered as a good result.

The second test area consists of two strips with 26 and 28 images, respectively.

2.2 Z/I Image Station

The workflow of automatical point measurements in Image Station Digital Mensuration (ISDM) is divided into two main parts: the relative orientation, where points are measured in single stereo models, and multiphoto orientation, where points in more than two images can be measured. It is also possible to start with multiphoto orientation directly. The control points have to be measured manually in at least one image using the absolute orientation menu item, and can then also be transferred to other images automatically using multiphoto orientation.

Automated measurement of tie points for relative orientation requires an initial manual measurement of two points in each stereo model before automated processing can be started successfully. The automated transfer of points between images of different strips is possible, and can be used to measure the tie points acquired during the relative orientation in corresponding images of the neighbouring strips. For the automated matching of both, relative and multiphoto orientation, a patch size of 9x9 pixels was used, combined with a number of 5 points maximum to be measured at each of the given 3 positions per image (6 per model). These positions follow the Gruber distribution, but can also be altered by the user to any other distribution. The correlation threshold, the value each measurement has to achieve to be accepted, was chosen to 0.95 and adapted down to 0.75 for single models. After performing the automated measurement with these parameters in relative orientation mode, it could be observed that at each position at least one point could be measured, usually more. Except for one model, the average parallaxes of the models were smaller than 10 microns. Afterwards, using the multiphoto orientation with automated point transfer, bundle adjustment could not be performed successfully due to the large parallaxes for points measured in more than two images, especially in the overlapping areas of strips. The same effect occurred in a second effort with manually measured tie points for strip connection. To clarify the reason for this exactly, some more investigations have to be done. Better results were achieved triangulating the first two strips of 54 images of the Nasca block, where manually measured tie points were used for strip connection. Figure 2 shows the distribution of the automatically measured tie points. In this project, points at almost every given position could be matched although especially strip 2 contains predominantly desertous areas, while some images contain agricultural crop land, which also can be classified as lowly textured. The position where matching failed significantly is marked in figure 2. As a global accuracy, 21.1 microns could be achieved after bundle adjustment, which is less than scan pixel accuracy.
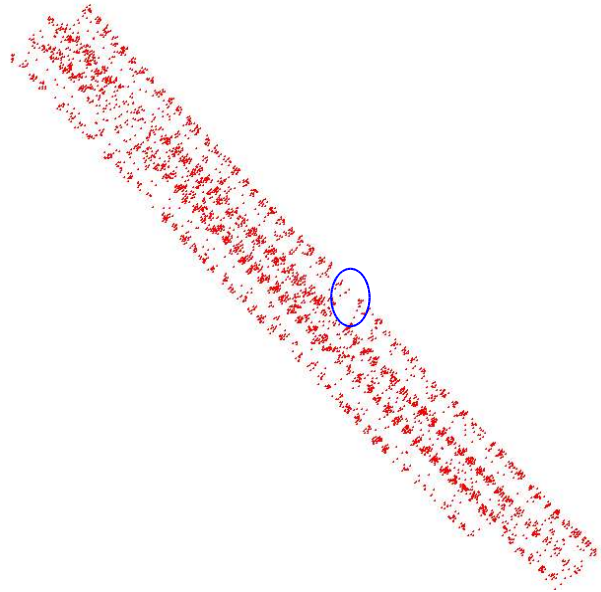

Figure 2: Distribution of automatically measured tie points using strip 1 and 2 (54 images)

2.3 Virtuozo 3.1

The test concerning aerotriangulation was performed using Virtuozo 3.1. At IGP, a license including aerial triangulation is available only for this version. In Virtuozo 3.1, no manual measurements are required for the initialisation of the stereo models, but for tie points between the strips. Using Virtuozo, like in Image Station, the user can influence the distribution of the tie point positions to be measured. Virtuozo supports Gruber and similar distributions and offers the user to choose the number of points to be measured at each position. Further parameters, like the ones mentioned above, can not be changed. The result of the automated tie point extraction in Virtuozo (figure 3) shows, that at several positions no tie points could be extracted. Performing bundle adjustment in PATB, a σ_0 of 6.97 microns was achieved. This value can not be compared directly to the result obtained from the analytical plotter because it is too optimistic due to the fact, that only points of high quality are included into the bundle adjustment, the weak points are completely ignored at the positions where gaps occurred. Thus, the calculated σ_0 does not consider instabilities of relative orientations resulting from missing tie points. In figure 3, red ellipses point up the areas where a significant accumulation of gaps in the tie point distribution appeared, compared to the manually measured points.

For the second subset of Nasca imagery, tie point extraction succeeded only for strip 1 although manual measurements for strip connection had been accomplished in each of the overlapping images. The mode for measurements of tie points for strip connection does not provide a zoom function, therefore the manual measurements were probably not exact enough for successful point matching.

For this reason, no directly comparable results could be achieved for automatic aerotriangulation, the presented results can only be considered as preliminary results of qualitative character.
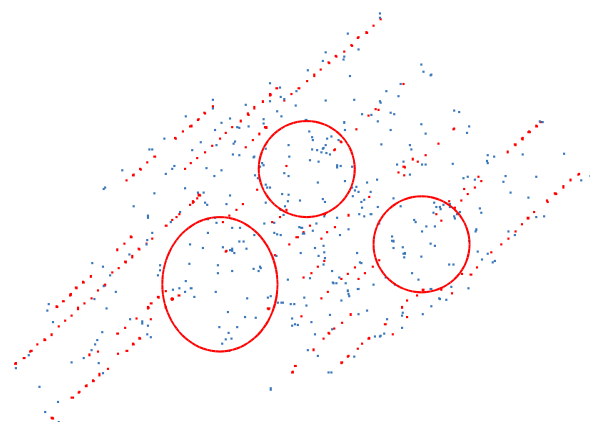
Figure 3: Distribution of tie points, red: automatically generated points, blue: manually measured points

3. DTM GENERATION

3.1 Reference data

In the area of investigation, no control points of superior accuracy exist. Thus, for the comparison of automatically generated DTMs, again accurate reference data measured on an analytical plotter Wild S9 was acquired using the software XMAP by Aviosoft™. For 5 stereo models from two strips, parallel profile measurements were performed with an average point distance of 20m along the profiles and a profile distance of 20m. Breaklines were not measured due to the flat areas except for model 116_117. Using our software DTMZ, grids with 5m mesh size were interpolated from the measured points. The grids then could be imported to ESRI ArcGIS™ 8.3 and directly compared with the grids acquired from the DIPS by calculating the height difference:

$$\Delta Z = Z_{DIPS} - Z_{REFERENCE}. \qquad (1)$$

From the resulting height difference grid, mean value, RMS error and the minimum and maximum offset were computed. Potential trends in the performance of height errors and their spatial distribution can be extracted. To visualise the distribution of the height errors, histograms of the differential grids and contour lines were produced, which allow for an examination of the geomorphological accuracy.

The topography covered by the processed stereo models is predominantly flat with only few discontinuities except for one model, consisting of the images 16 and 17 in the first strip, which contain parts of 3 quebradas (figure 1).

For DTM generation, the orientations computed using Image Station Digital Mensuration were transferred to the analytical plotter and used for the manual measurements. On Virtuozo, 4 control points per stereo model, transferred from ISDM, were used for absolute orientation of the images. To minimise the marginal differences caused by varying spatial attitudes and positions of the projective centers, Geomagic Studio 4.1 by Raindrop Geomagic Inc. was used to register the automatically derived DTMs to the reference data applying the global registration function.

3.2 Image Station™

The method of DTM generation applied by Image Station Automatic Elevations (ISAE) is described in detail in the manual which is integrated in the graphical user interface (Z/I Imaging Corporation, 2002). For each level of the image pyramid, an initial DTM is derived by matching homologous points, starting with a horizontal plane in the first level. From this initial DTM, a DTM is modeled with bilinear finite elements which then serves as the initial DTM for the next level. For matching, ISAE uses the interest operator and correlation coefficient while the matching area is geometrically defined by a parallax bound and the epipolar line.

ISAE offers a lot of different strategies for DTM generation. Users can choose different terrain types, adaptive or non-adaptive grid, parallax bound and matching modes, correlation thresholds or define terrain types by themselves. Different smoothing filters with user-defined weights and sampling factors can be applied. Some tests with the default terrain types showed, that the best results could be achieved using terrain type "flat" with adaptive mode. The patch size for crosscorrelation was set to 9x9 pixels and the smoothing filter was set to "high", keeping the default values for smoothing weight (2.0) and sampling factor as recommended in the manual. After a first attempt with a correlation threshold of 0.95, a value of 0.75 was chosen because of the low point density and thus a strong terrain filtering achieved with 0.95. The result is a grid with 5m mesh size which the software interpolates from the measured points.

The height differences obtained for the different models show clearly, that not only texture but also terrain characteristics, especially steep slopes like on the border of the valleys in the images 16 and 17, affect the accuracy of the automatically generated DTMs. Table 1 shows the mean height error, its standard deviation and the minimum-maximum range of the height differences between the automatically derived DTM and the manually measured DTM.

Table 1: DTM generated using Image Station compared to the manually measured DTM on an analytical plotter Wild S9

Model	ΔZ	Std. Deviation	Min. – Max.
116_117	0.25m	3.10m	-19.1m – 24.2m
210_211	-	-	-
211_212	0.22m	1.99m	-4.4m – 36.4m
212_213	0.25m	1.53m	-6.3m – 18.8m
213_214	-0.02m	1.33m	-12.9m – 7.0m
223_224	-0.01m	0.77m	-3.3m – 7.6m

Mean height errors, standard deviations and the minimum-maximum-ranges of the different stereo models show a noticeable heterogeneity. In model 210_211, for an unresolved reason no correct DTM could be calculated.

The differential grid of model 116_117 shows another phenomenon: The big blunders show a coincidence with areas of steep slopes and are predominantly positive (figure 4).

Figure 4: Differential grid of model 116_117 (ISAE), positive errors are bright, negative errors dark

Another effect, influencing the geomorphological correctness of the DTM, is the smoothing in the Image Station measurements caused by interpolation. Missing terrain information like marked in figure 5 is the consequence.

From the achieved results for Image Station, no trend for ΔZ can be derived for the single matched points because the generated DTMs are affected by the ascertained smoothing effect which depends on the terrain characteristics.

To reduce the smoothing effect, the DTMs were generated with different filter settings (low, medium and high), but the accuracy did not increase significantly. Compared to earlier investigations (Grün et al., 2000), where an RMS error of 0.7m for Palpa imagery was achieved with ISAE with DTM interpolation of the matched points done with DTMZ, this indicates that the interpolation module of ISAE determines the main part of the height errors. Terrain elevations and sinks of a size up to 100 by 50 metres are modeled as flat terrain and cause blunders in a magnitude of 10 to 20 metres in model 116_117 (figure 5).
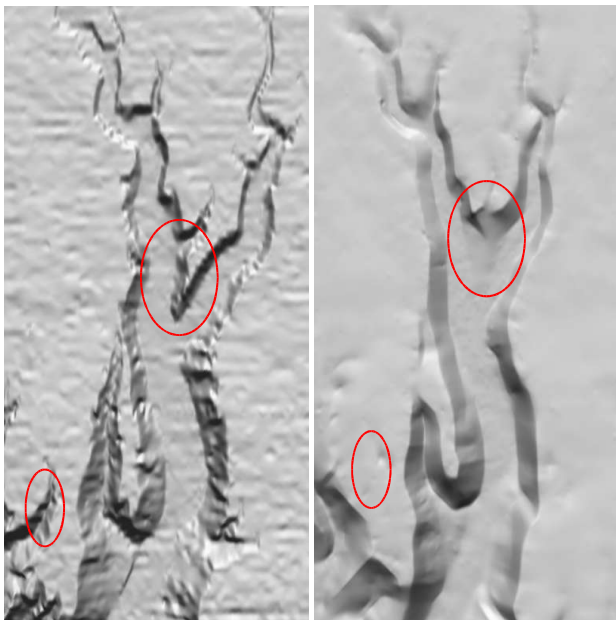

Figure 5: Manually measured DTM (left) and automatically derived DTM using ISAE (right). Marked red: Loss of geomorphological information due to strong smoothing.

3.3 Virtuozo™ 3.1/3.3

Unlike Image Station, Virtuozo uses epipolar images for automatic DTM generation. The algorithm consists of crosscorrelation and a global relaxation matching technique for blunder detection (Baltsavias et al., 1996). The points are calculated based on a regular grid in image space, and therefore the calculated DTM has to be interpolated subsequently. For the comparison of the generated DTMs, digital terrain models were calculated using both versions available at our institute, 3.1 and 3.3, to investigate whether an improvement in matching algorithms affects the obtained results. In Virtuozo, like in Image Station, different strategies for DTM calculation can be chosen by the user. It distinguishes between flat, undulated, hillock, broken and rugged areas. Further parameters that can be influenced are the patch width and height. The value was set to 9 pixels for both width and height for this test. An integration of manually measured breaklines to refine the matched points is also possible. After matching, a visual quality control can be accomplished. The matched points are visualised in the stereo model, divided into 3 classes (red, yellow, green) where the yellow and the green classes contain the more or less reliable points and the red class consists of the unreliable matching results. There is no detailed description of the point classification in the user manual (Supresoft Inc., 1999). To compare them to the reference data set, the points resulting from the matching process still had to be interpolated to a grid, in this case with 5m mesh size using DTMZ.

Table 2 shows the results obtained with Virtuozo 3.1 compared to the manual measurements, while table 3 contains the results for the DTMs generated using Virtuozo 3.3.

Table 2: Results of the DTM-comparison Virtuozo 3.1 vs. the manual measurements

Model	ΔZ	Std. Deviation	Min. – Max.
116_117	0.17m	2.95m	-17.2m – 18.4m
210_211	-0.03m	1.00m	-9.5m – 6.7m
211_212	0.08m	0.74m	-4.5m – 5.5m
212_213	-0.06m	1.35m	-24.9m – 11.9m
213_214	-0.03m	0.98m	-10.8m – 8.3m
223_224	0.02m	0.64m	-5.2m – 4.3m

Table 3: DTM generated with Virtuozo 3.3 compared to the reference DTM

Model	ΔZ	Std. Deviation	Min. – Max.
116_117	0.35m	2.66m	-15.9m – 16.8m
210_211	0.04m	0.81m	-5.6m – 7.7m
211_212	0.13m	0.73m	-6.1m – 4.2m
212_213	0.13m	1.20m	-5.3m – 18.6m
213_214	0.02m	1.03m	-10.7m – 7.4m
223_224	-0.01m	0.65m	-5.2m – 4.3m

Generally, the standard deviations of the measurements produced by Virtuozo 3.3 are marginally smaller than the ones from version 3.1. Also the minimum-maximum ranges become more narrow in the most models. For both automatically generated datasets, the mean height errors are homogeneously close to 0m, having similar standard deviations between 0.65m and 1.35m. Model 116_117 shows a significant difference: the standard deviation of 2.66m and the larger minimum-maximum range for the DTM generated by Virtuozo 3.1 compared to the smaller values of version 3.3 is a sign of larger blunders.

In model 116_117, like in the DTM generated with Image Station, the most blunders occur on the steep slopes, while the height error distribution in the flat areas is very similar for both systems.

Unlike the smoothing effect occuring in the Image Station datasets, both Virtuozo software versions produce very rough surfaces (figure 6). A loss of geomorphological information as appearing in the Image Station data (figure 5) is not obvious.

The results of both tested versions of Virtuozo achieved similar results, except for the models 116_117 and 212_213. In both cases, version 3.3 achieved a smaller standard deviation and minimum-maximum range. Generally, the values for ΔZ show that Virtuozo 3.3 tends to measure slightly higher than Virtuozo 3.1 but seems to be less affected by blunders especially for the two problematic models 116_117 and 212_213.
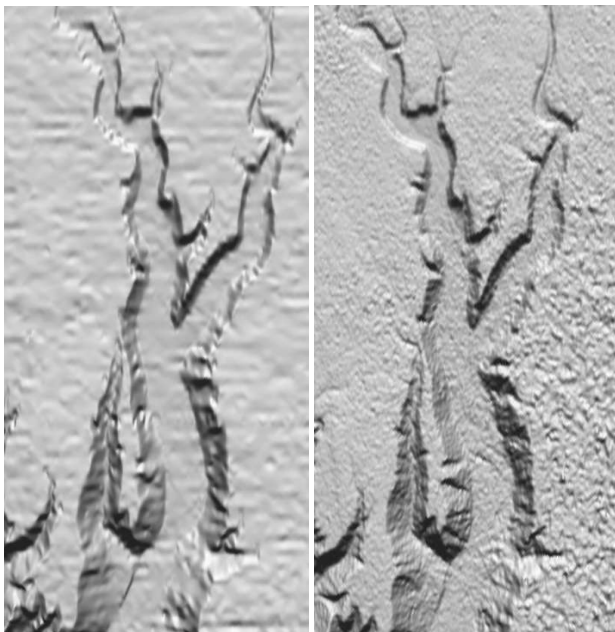

Figure 6: Manually derived DTM (left) and DTM generated by Virtuozo 3.3 (right)

3.4 Comparison

Figures 5 and 6 visualise the general difference between the acquired DTMs on Image Station and Virtuozo: On the one hand, a strong smoothing effect in the Image Station data and on the other hand the rough surface produced by Virtuozo 3.1/3.3.

The accuracies resulting from the comparison of the acquired DTMs (tables 1,2 and 3) show, that in average the Virtuozo system has mean height errors close to 0m with standard deviations mostly between about 0.7m and 1m while the data produced on Image Station differs with a larger variance between about 0.7m and 1.6m in the models covering flat terrain. Both systems show problems in model 116_117, where Virtuozo exceeds standard deviations of 2.5m and Image Station obtains 3.1m. Furthermore, a strong smoothing effect causes a loss of geomorphological information especially in rough terrain (compare figure 5) The differences between manually measured and automatically derived data are caused by the steep slopes in this model, as shown in figure 7.

Concerning the flat areas, both systems achieved throughout good results wihtout big blunders or gaps. Contour lines from a subset of model 116_117, the model for which the worst results

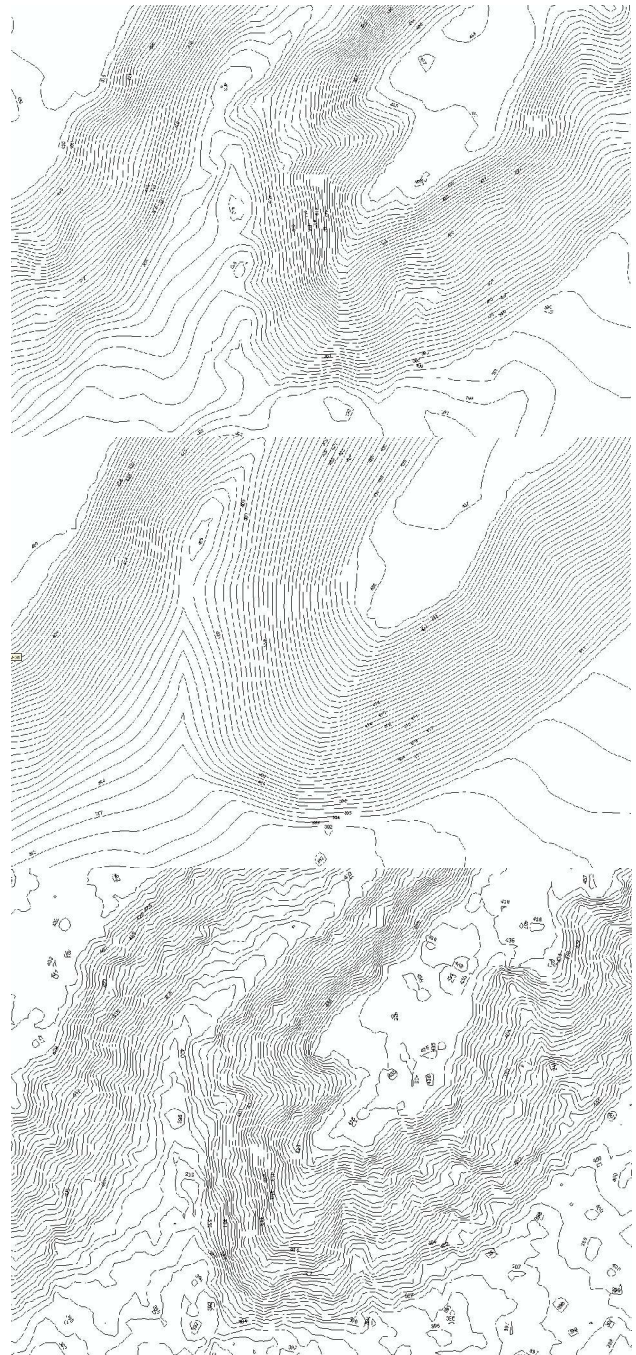in terms of standard deviations were obtained due to the slopes, are comparatively illustrated (figure 7).

Figure 7: 1m contour lines: Wild S9, Image Station and Virtuozo 3.3 from top to bottom (Model 116_117).

Compared to the contour lines derived from the manually measured DTM, the contour lines based on the Virtuozo measurements are more detailed regarding geomorphological information while the contour lines based on Image Station measurements are too smooth.

A comparison of the contour lines for the model with the best result (223_224), derived from Image Station and analytical plotter, with the difference grid shows that the errors of Image Station data result from the smoothing applied during DTM

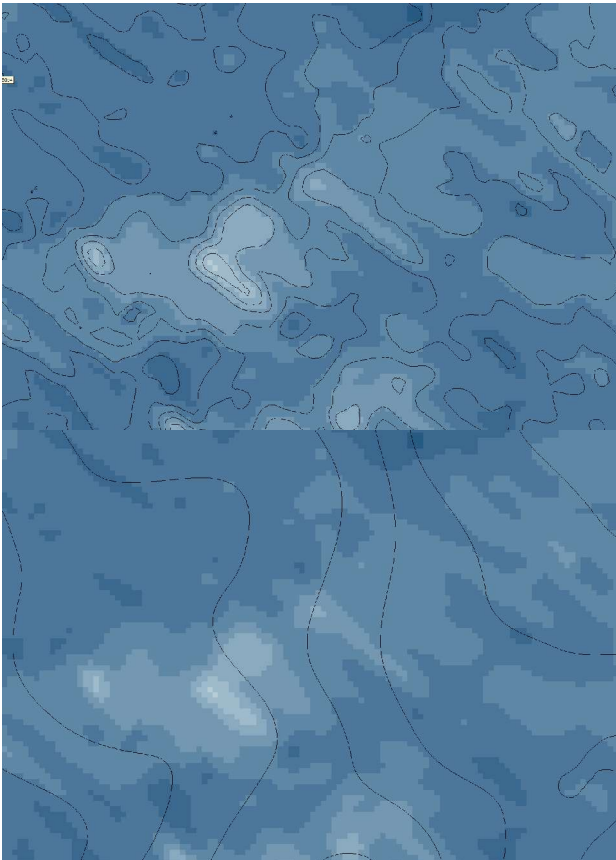interpolation (figure 8). It is clearly visible that morphological details are not considered in a sufficient way.

Figure 8: Exemplary comparison of the derived contour lines from analytical plotter (top) and Image Station (bottom) for model 223_224, overlaid on their height difference grid, respectively. Positive height differences are bright, negative differences dark.

4. CONCLUSIONS AND FUTURE WORK

The investigations accomplished so far have shown, that a fully automated image processing for aerotriangulation and DTM generation does not provide results that are as reliable as the reference data measured on an analytical plotter. Concerning aerotriangulation, for the Nasca project a feasible solution would be semi-automated processing using the automated tie point extraction of a digital photogrammetric workstation enhanced by manual measurements in areas of weak point density.

DTM generation can be advanced considerably with digital photogrammetric workstations, compared to manual measurements on analytical plotters. However, the performed tests show that the terrain characteristics affect the obtainable accuracy and reliability significantly. Manual measurements and extensive post editing are required to achieve results which hold the accuracy level of analytically generated DTMs.

The problematic results do not occur in the flat areas with homogeneous texture, where perhaps the automatically derived DTMs are even more accurate than the manually measured DTM due to their high density of matched points. The large blunders, which require manual editing, are mainly located on the steep slopes.

Further investigations on an automated processing of Nasca imagery will be done on an internally developed software package for DTM extraction. First tests, which produced no satisfactory results, have shown, that the software still needs to be improved on aerial imagery. Commercial software packages, including Virtuozo and Image Station, will be further examined regarding aerotriangulation and DTM generation. Especially for Image Station, a direct investigation of the matched points could possibly lead to better results if external DTM interpolation software is used.

Another topic is the integration of manually measured breaklines as pre known data into the matching process for automatic DTM generation, which could improve the accuracy in areas containing discontinuities, but would increase the cost due to the required manual measurements.

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