COMPARISON OF DSMs GENERATED FROM MINI UAV IMAGERY AND TERRESTRIAL LASER SCANNER IN A CULTURAL HERITAGE APPLICATION

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IC WG I/V Autonomous Vehicle Navigation

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ABSTRACT:
In this paper we present two different methods, which were applied for the DSM generation of the cultural heritage site Pinchango Alto. The area of interest is a LIP (Late Intermediate Period; 1400 AD) settlement, situated 400 km in the south of the capital of Peru (Lima) close by the famous Geoglyphs of Nasca. The site was recorded using a terrestrial laser scanner (Riegl LMS-Z420i) and a mini UAV-system (Unmanned Aerial Vehicle) under the framework of a research program called NTG ("New methods and technologies in the humanities"). During the field work, using both methods, the complete settlement was documented in a short time. The post-processing of the data was done by use of in-house developed software packages. The image data (UAV) were oriented and a DSM (10 cm resolution) was generated automatically using a multi-image matching approach. For the registration of the single laser scans a surface matcher rather than the special targets was used. As a product of the laser data a regular raster grid with point spacing of 5 cm was generated. The 3D comparison of both elevation models shows a mean value less than 1 cm with a standard deviation of 6 cm. The main discrepancy between the data sets results mostly from occlusion, caused on the restricted viewing directions of the acquisition stand points. The presented data acquisition and processing methods showed their high usability for the documentation of archaeological sites.

1. INTRODUCTION

Pinchango Alto is a LIP (Late Intermediate Period) site in the Nasca/Palpa area (Fig. 1) and has recently been studied in the framework of the Nasca-Palpa Archaeological Project (Reindel and Gruen, 2005). The site is located about 40 km northwest of the modern town of Nasca on an elongated rocky spur on the western slope of Cerro Pinchango. It is framed by deep ravines on three sides, making access from both Río Grande (to the north) and Río Palpa (to the south) difficult. The central part of the site covers an area of roughly 3 ha on the flat ridge of the spur. The ruins are composed of partially collapsed double-faced walls built of unworked stones, today preserved to a maximum height of about 1.5 m (Fig. 2a). These walls once formed agglutinated rooms, enclosures, corridors, and several large plazas. In general, the site is quite well preserved, the southwestern and northeastern sections being in a better shape, allowing to recognize e.g. doorways in the walls. Due to its hidden location, the site has suffered less looting than most other sites in the region of Palpa and Nasca (Eisenbeiss et al., 2005b).

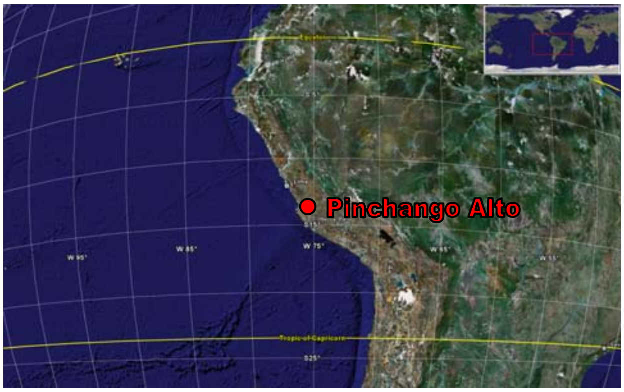

Figure 1. A snap shot from Google Earth® (http://earth.google.com/) showing the location of Pinchango Alto.

(a) (b)

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Figure 2. The autonomous flying Model-Helicopter (a) and the Laser-Image Station (b) during the measurement campaign in Pinchango Alto.

Because of its state of preservation, Pinchango Alto is well suited to study a typical LIP site in detail. However, the rugged topography renders access to and working on the site very difficult. During the annual field campaigns in the Palpa region, time and manpower available for site surveying are limited. A series of vertical aerial images of the region, taken in the framework of a geoglyph survey (Lambers, 2006), did not provide enough detail for a photogrammetric survey. Thus, a highly mobile, flexible, and efficient recording system was needed to record the preserved architecture, as well as the terrain (Eisenbeiss et al., 2005b).

The site was documented under the framework of a research program called NTG ("New methods and technologies in the humanities") funded by the German Ministry of Education and Research (BMBF, Bonn). The project aims to investigate the applicability of modern surveying techniques to archaeological documentation studies in terms of accuracy, efficiency, speed and feature resolution.

Two systems, a terrestrial laser scanner and a UAV (Unmanned Aerial Vehicle) system, were employed during the September 2004 field campaign. The field work was conducted in cooperation with Riegl Laser Measurement Systems (Austria), Helicam and weControl (Switzerland), the German Archaeological Institute (KAAK Bonn (Germany)) and the Group of Photogrammetry and Remote Sensing of ETH Zurich (Switzerland). Further information can be found on the project webpage[2].

A model helicopter carrying a still-video camera was used to acquire a series of aerial images in a single day. The photogrammetric processing of those images was carried out at ETH Zurich. The results have been presented in Eisenbeiss et al. (2005a, 2005b).

A Riegl LMS-Z420i laser scanner kindly provided by Riegl Measurement Systems GmbH, Horn (Austria), was used to scan the whole area in 5 days. For registration of the point clouds, retro-reflective cylindrical targets (Standard cylinders by Riegl GmbH) were used. More details about the data acquisition and post processing with RiSCANPRO (Riegl) were given in Gaisecker (2005).

Surface based registration is an alternative technique to the target based ones. The Pinchango Alto laser scanning data set was registered using an in-house developed surface matcher, called Least Squares 3D Surface Matching method (LS3D) introduced by Gruen and Akca (2005), as well. The mesh generation and modeling was performed using Geomagic Studio 6. The Pinchango Alto data set is an extreme case due to huge data volume (totally 144 million points) and large occlusions.

For comparison purposes a manually measured DSM of a sub-part of the area was generated using the model helicopter images. These three DSMs, so called UAV-DSM, Laser-DSM and manual-DSM, are compared and analyzed with respect to accuracy, resolution and applicability to upcoming archaeological tasks.

[2] http://www.photogrammetry.ethz.ch/research/pinchango

The outline of the paper is as follows. The next chapter explains the data acquisition phase. The technical specifications of the UAV system and the laser scanner are given as well. Chapter three gives the post processing chain both for UAV and laser data. Chapter four presents the results of comparisons and analyses.

2. DATA ACQUISITION

During fieldwork, we determined the positions of 80 signalized ground control points (GCPs) to be used for both laser scan data and UAV image orientation. The GCPs were regularly distributed over the site. Retro-reflecting cylinders were mounted on circular white cardboard discs and affixed to stones with a special glue easily removable without traces (Fig. 3). While the reflectors were clearly marked in the laser scan point clouds, the cardboard discs were discernable in the aerial images.

Figure 3. A signalized control point for both laser and UAV data orientation.

The GCPs were measured with RTK GPS (Real Time Kinematic Global Positioning System) and have a accuracy of 2-3 cm in planimetry and up to 5 cm in height. Some of the GCPs moved or fall down during the field campaign, because of dew in the morning and wind in the afternoon. These were not used in the post processing of the data (Eisenbeiss et al., 2005b).

The high number of control points was needed because of the registration of RiSCANPRO which uses the target based registration method (Gaisecker, 2005).

2.1 The UAV system

For the documentation of Pinchango Alto a standard helicopter or airplane with photogrammetric cameras would be too expensive and moreover was not available in the area of Palpa/Nasca. Further on, these platforms did not allow flying close to the object and they do not have the capacity for complicated manoeuvring processes.

In the early stages of the project, a balloon was considered for image acquisition. Balloons are unstable in the air and they do not allow acquiring fast images and they can not easily be navigated according to a flight plan.

Since mini UAVs fulfil all these conditions, we opted for using this kind of platform for the image acquisition. More details about UAVs can be found in UVS-international (2006), for more information about rotary wing based UAVs see Eck (2001), Eisenbeiss (2004), Saggiani and Teodorani (2004).

For data acquisition, an autonomous model helicopter the Copter 1B from Survey-Copter (Survey-Copter, 2006), which is equipped with the flight control system from weControl

(weControl, 2006), was selected. This autonomous helicopter features a GPS/INS based stabilized flight control system and has a flying range of up to 2 km, a flying altitude over ground of up to 300 m and is characterized by high manoeuvrability. With this type of UAV, it is easy to fly above difficult accessible areas like Pinchango Alto.

The operation of this kind of model helicopters still requires a trained pilot for safety reason, since the autonomous take off and landing in rough terrain is not solved for all scenarios yet. Additionally, an operator with photogrammetric background was needed for the operation and the control of the image acquisition in Pinchango Alto. The main units of the platform are helicopter frame, engine, navigation system, GPS-antenna, gas tank, damped camera mounting and the mounted camera Canon D60 (see Fig. 2a). The components of the flight control system are documented in more detail in Eisenbeiss et al. (2005a), weControl (2006).

2.2 Image acquisition with UAV system

The flight trajectory and the image acquisition points were previously calculated, based on the image scale, camera parameters, maximum flying height of the model helicopter, dimension of the area (300 m x 150 m) and the overlap in and across the flying direction (75 %). For the flight planning we also took into account that the images should have a high overlap, since our in-house developed Multiphoto Geometrically Constrained Matching (MPGC) algorithm allows to match points in multi images and therewith the accuracy and reliability of the point measurements would be increased (Zhang, 2005).

Finally, 85 UAV-images were taken in 5 strips in a net total of 1 hour flight time. The mission had to be split up into 3 parts for the reason of refuelling and battery charging. Therefore, during one day of field work, we could acquire 95 % of the planned image data (Eisenbeiss et al., 2005a). Apart of that, this was the first time that the system was used in a longer-lasting photogrammetric mission.

The model helicopter, the flight planning and the data acquisition are described more in detail in Eisenbeiss (2004) and Eisenbeiss et al. (2005a, 2005b).

2.3 The Laser Scanner

The Riegl LMS-Z420i scanner (Fig. 2b) was mainly chosen for its long scanning range of 1000 m and the combination with a digital still-video camera. Its accuracy is of ± 10 mm (single shot) and ± 5 mm (averaged) with a beam divergence of 0.25 mrad (25 mm spot size @100m). Further features include: a measurement rate of up to 8000 pts/sec, a field of view of up to 80° x 360°, and a digital camera Nikon D100 (Riegl, 2006).

2.4 The scanning campaign

The scanning campaign had been completed in 5 days of fieldwork. The whole area was covered with 61 scans, only 57 of which were registered. The remaining 4 scans were not used, since they cover the southern cliff part of the site which is not directly of interest, and due to insufficient overlapping with scans of the main area.
The area of the well preserved walls (Area 1 in Fig. 4) was scanned in the first 3 days. In the continuing days the remained part (Area 2) of Pinchango Alto was scanned with a lower point density level. Totally 144 million of points acquired in 57 scan files. The point spacing is between 1-35 cm, changing with the range.

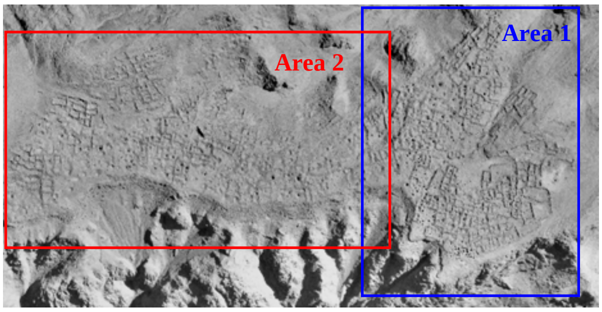

Figure 4. Pinchango Alto, cut-out from an orthophoto generated from of aerial images (1:7000) with Area 1 and Area 2.

3. DATA PROCESSING

3.1 Photogrammetric processing of UAV imagery

The UAV imagery were processed using different software packages (see Fig. 5). As a first attempt the tie points were generated automatically using LPS Core. The results turned out to be error-prone as LPS Core is designed for the standard aerial case. Therefore, we decided to initially measure some few manual seed points and then to run the automatic tie point measurement tool. This procedure still yielded large number of blunders in mountainous areas (Eisenbeiss et al., 2005a).

The measured tie points were exported to an in-house developed bundle adjustment software (BUN). BUN detected more blunders than LPS Core. LPS Core achieved a RMSE of residuals of 6 cm. BUN, performing self-calibration with Brown's model, excluding the shear and tangential lens distortion parameters, obtained a RMSE of residuals of 1 cm (1/3 pixel).

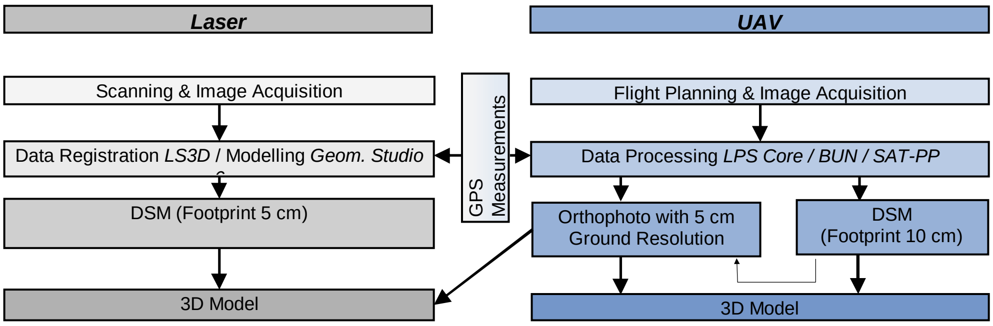

Figure 5: Simplified workflow for the processing of the laser scanner and UAV data.

For the generation of UAV-DSM our in-house developed software SAT-PP (Zhang, 2005) was used. SAT-PP was originally developed for linear array sensors. For the processing of the Pinchango Alto dataset, the sensor model of frame cameras was adapted such that the multi-image matching algorithm could be applied. At least three images could be used for matching of each section of the Pinchango Alto data set. Using SAT-PP, finally a DSM (4.7 million points) with a resolution of 10 cm was produced automatically.

An orthophoto mosaik was generated for 3D visualization and archaeological analysis purposes as well. (Eisenbeiss et al., 2005a).

Furthermore, the manual-DSM was produced covering only Area 1 (Fig. 4), because the manual measurements were to time consuming. These measurements are well suited in order to help to identify errors in the Laser- and UAV-DSM. The average distance between the manually measured points were defined to 50 cm.

Since automatically generated DSMs (Laser and UAV) have a resolution of 5 and 10 cm respectively, the manual measurements can presumably identify trends and the results allow saying which data suite better to the reality. The manual measurements will not discover blunders of small features, like single stones, and small modelling problems, but accessorily blunders in the data like persons in the laser scan or miss-matched points from the matching procedure will be detected.

3.2 Processing of the laser scanner point clouds

3.2.1 Registration: target based versus surface based

Terrestrial laser scanning companies (e.g. Z+F, Leica, Riegl) commonly use special kinds of targets for the registration of point clouds. However, such a strategy has several deficiencies with respect to fieldwork time, labour, personnel and equipment costs, and accuracy. In a recent study Sternberg et al. (2004) reported that registration and geodetic measurement parts comprise 10-20% of the whole project time. In another study a collapsed 1000-car parking garage was documented in order to assess the damage and structural soundness of the structure. The scanning took 3 days, while the conventional survey of the control points required 2 days (Greaves, 2005). In our work at Pinchango Alto 2 persons set the targets to the field and measured with RTK-GPS in 1½ days.

Not only fieldwork time but also accuracy is another important concern. The target based registration methods cannot exploit the full accuracy potential of the data. The geodetic measurement naturally introduces some error, which might exceed the internal error of the scanner instrument. In addition the targets must be kept stable during the whole scanning campaign. This might be inconvenient with the scanning works more than one day.

Surface based registration techniques stand as efficient and versatile alternative to the target based techniques. They simply bring the strenuous additional fieldwork of the registration task to the computer in office while optimizing the project cost and duration and achieving a better accuracy. A good literature review related to surface based registration methods can be found in Gruen and Akca (2005).

For the point cloud registration the LS3D surface matching method (Gruen and Akca, 2005) was used. It estimates the transformation parameters between two or more fully 3D surfaces, using the Generalized Gauss-Markoff model, minimizing the sum of squares of the Euclidean distances between the surfaces. This formulation gives the opportunity of matching arbitrarily oriented 3D surfaces simultaneously, without using explicit tie points.

3.2.2 Pair wise registration with the LS3D surface matcher

The Pinchango Alto laser data set is a good example of large volume data sets with 144 million points from 57 stand points. Only the raw XYZ files in ASCII format occupy 3.83 GB memory area on a hard disk. Owing to our efficient boxing structure the large data size is not a problem at the registration phase from the data management and processing time point of views. However we faced with many limitations at the modeling phase, which will be explained later.

Figure 6. Top view of the point cloud of a sub-part of a scan.

Due to the topography of the site and relatively large incident angles of the signal paths large occlusions occurred in the point clouds (Fig. 6). This is a difficult case for the surface registration problem. However our surface matching algorithm LS3D successfully handled this problem.

Totally 130 consecutive matching processes were performed using the LS3D matching method. No divergence or failure case occurred. The average sigma naught value is around 1.0 cm, which confirms the reported accuracy potential of the LMS-Z420i scanner.

3.2.3 Global registration

In the LS3D matching processes, the final correspondences were saved to separate files. The number of tie points was thinned out by selecting of every 10^{th} correspondence. Then all these files were given as input to the block adjustment by independent models software BAM7, which is an in-house software based on a 7-parameter 3D similarity transformation. The first scan (#01) was selected as the reference, which defines the datum of the common coordinate system. It was run in the rigid body transformation mode by fixing the scale factor to unity. The block adjustment concluded with 0.5 cm *a posteriori* sigma value.

3.2.4 Georeferencing

The point clouds have been registered in the reference system of the first scan. A final rigid body transformation was applied in order to transform the point cloud from the local coordinate system to the coordinate system of the GCPs. 48 well distributed GCPs were identified on the intensity image of the scans, and used as common points between the two systems. A posteriori sigma naught of the adjustment was 4.1 cm, which is comparable with the accuracy of the GCP measurements.

3.2.5. Surface modeling with Geomagic Studio 6

After the registration all scan files were merged as one XYZ file, discarding the no data or the scanner signed erroneous points, e.g. scan points on the sky. This file totally contains 78.1 million points. It was further cropped to contain only the area of interest, finally with 69.2 million points.

As a first attempt the mesh generation was tried at the original data resolution. The software recommended setting the target number of triangles to 2.5 millions, which is clearly suboptimal. When this recommendation is ignored, the operation could not be performed, since the memory request of the software exceeded the physical memory limit 2 GB of the computer.

The number of points was reduced to 14.8 million point using the "grid sampling" function with a 5 cm grid size. Then the point cloud file was split to two files to overcome of memory limitation. This was done manually, since the software does not provide any automatic solution. Finally surface wrapping was done for both parts separately with a medium level noise reduction option.

All the displaced objects during the 5 days fieldwork, e.g. people, GPS, bags, boxes, etc., produced errors in the generated mesh. Those errors were edited manually. Because of data unavailability some holes occurred on the meshed surface. Missing data parts are usually due to occlusions of walls and the hollows. They were filled with the "Fill Holes" function of the software. After the editing step those two meshed surface parts were merged as one manifold. The final model contains 5.8 million triangles.

4. COMPARISON

The 3D comparison of the different elevation model was done with Geomagic Studio. Geomagic Studio has the capability to perform 3D comparison between point to surface or surface to surface models.

We used the following datasets for comparison: UAV-DSM, Laser-DSM and manual-DSM. The laser model covers the complete Pinchango Alto area. The UAV-DSM covers 95 % of the settlement area, since the UAV flight could not be finished due to some technical problems. The manual measurements cover only Area 1 (Fig. 4).

The laser data with 5 cm resolution has a higher point density compared to the DSM model (10 cm) produced with SAT-PP and therefore single stones, freestanding and stones from the walls can be modeled. The image scale (1:4000) did not allow us to detect more details and a better scale would have produced more cost for the data acquisition and processing.

Table 1: Results from the comparison of the different DSM datasets.

	Laser/ SAT-PP	Laser/ Manual	SAT-PP/ Manual
Std. deviation [m]	0.06	0.11	0.10
Mean [m]	< 0.01	< 0.01	< 0.01
Max [m]	0.54	0.66	0.46

The comparison between the Laser- and the UAV-DSM show a mean difference of less than one centimeter with a standard deviation of 6 cm (see Table 1 and Fig. 7). The slightly high standard deviation could be explained by outliers. These differences occur mainly where the topography changes suddenly, e.g. walls elongated along the flight direction, at the border areas of the settlement and inside the holes (mine entrances). The maxima value was found on a wall (see Fig. 8 upper image series). This wall was modeled well using the laser data, since one laser point cloud was taken from the side of the particular wall. Since, we had no additional strip, which covers the wall from a lateral view point, the wall could not be modeled appropriately from the UAV images. This problem could be solved using additional images taken in an additional across track strip or oblique images.

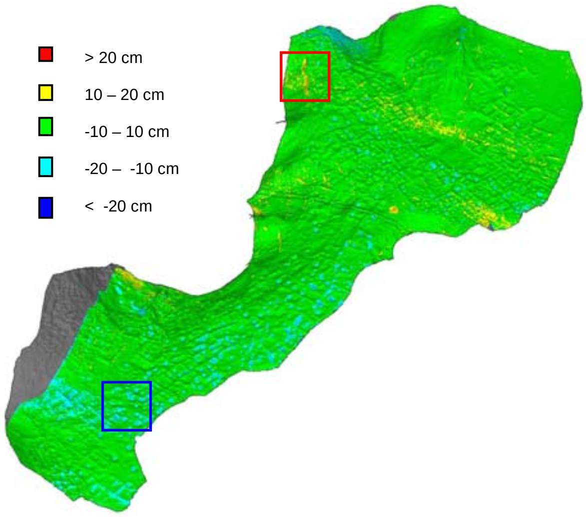

Figure 7. Discrepancy map of 3D distances of UAV-DSM and the Laser DSM after registration.

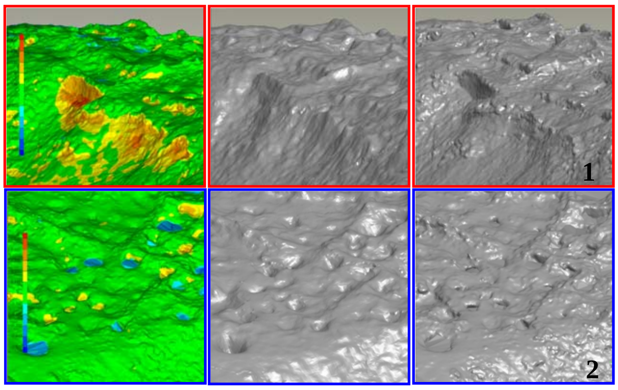

Figure 8. Detailed view of 1 & 2 in Fig. 7. 1: Example for the maximum difference of DSMs forthcoming on walls; 2: Example for mining entrances (holes).

The second example from Fig. 8 shows the area with a big deposit of mine entrances. In this case the laser signal did not reach inside the holes due to terrestrial acquisition geometry. A laser scanner mounted on the model helicopter could help to fill these gaps. In this area the DSM produced from the images fits better to the reality due to the fact that UAV images have more suitable coverage than laser data.

In Table 1 the results from the comparison of Laser- and UAV-DSMs against to the manual-DSM are shown. Both of them showed similar good results with respect to the manual-DSM. The mean difference is less than one centimeter. The standard deviation is approximately 10 centimeter and the maxima value

of difference is less than 0.5 m for the UAV-DSM and 0.7 m for the Laser-DSM respectively. The maxima were mainly found in the mining and wall areas.
Both generated elevation models have shown their high suitability for the 3D-documentation of the settlement Pinchango Alto.

5. CONCLUSIONS

In this work we have shown two data acquisition techniques for the documentation of an archaeological site. Both, the terrestrial laser scanner and the mini UAV-system satisfied our expectation. We could capture the data with the UAV and laser scanner in 1 and 5 days of fieldwork, respectively. Furthermore, we generated an UAV-DSM out of the UAV image data, using our developed multi-image matching algorithm, automatically with 10 cm resolution. The laser data were registered by the Least Squares 3D Surface Matching method (LS3D) successfully without using targets. Finally, a Laser-DSM with 5 cm resolution was interpolated. Post processing of both, laser and UAV data, was finished in 2 weeks of work. One week of work was additionally needed for the manual measurements.

The comparison between the UAV- and the Laser-DSM showed slightly better results as the comparison of the UAV- and Laser-DSM with manual measurements. Furthermore, the manual measurements are more time consuming with respect to the automated methods. Therefore, the automated methods are preferred instead of the manual ones.

In that, the resolution of the laser is higher, single structures like stones could be seen in the laser elevation model. On the other hand, in both data sets blunders occur. For the UAV-DSM, the main difficulties were on walls and structures with vertical surfaces, which were not covered in different image strips. The laser could not acquire points in the holes (mining entrances), therefore the UAV-DSM fit better in these areas.
Using the advantages of both data sets, in future work we can combine them to a more precise elevation model. Furthermore, this data set could be integrated in a global elevation model, which will be supportive for upcoming archaeological interpretations.

For archaeological analysis, the UAV image data have the most usability, since the image data could be used for the automated generation of elevation model and for manual measurements in stereo viewing mode. For definition of the walls, rooms, forecourt etc., the stereo images give valuable information for the interpretation by archaeologists. On the other hand the Laser-DSM can be used for interpretation of the architecture of single walls and rooms due to the high point density.

According to our experience for future projects it would be more suitable to use a laser scanner and a camera mounted on a mini UAV, because more viewing directions are possible from an airborne platform, e.g. nadir or oblique. Further on, the post processing time can be reduced by employing efficient algorithms in the processing chain for identification of seed and tie points as well as for the reduction of control points and for the laser data processing.

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