Pinchango Alto – 3D archaeology documentation using the hybrid 3D laser scan system of *RIEGL*

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ABSTRACT: We present a 3D documentation of an ancient mining settlement using *RIEGL'S* hybrid 3D laser scan system consisting of the high-performance 3D imaging laser sensor Z420i and a mounted high-resolution camera.

1 INTRODUCTION

Pinchango Alto, a hilltop site of the Late Intermediate Period (1000-1400 AD) in Palpa, on the south coast of Peru, is supposed to be an ancient mining settlement where gold bearing minerals have been processed. We report on the extensive survey carried out in order to gain and a detailed site plan making use of laser scanning and photogrammetrical methods. As the site is situated on an outlying plateau all the equipment had to be carried over rather long distances through a deep canyon southwest of the area of interest (see Figure 1).

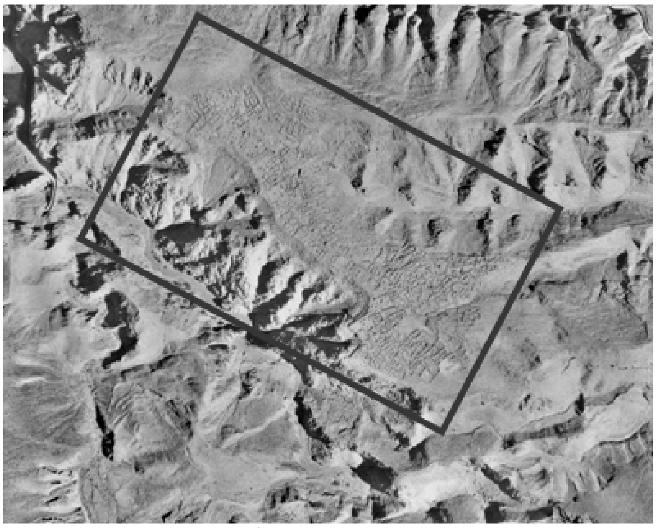

Figure 1. Aerial view of Pinchango Alto

2 COMBINATION OF LASERSCANNING AND PHOTOGRAMMETRY

Laser scanning has already shown its outstanding advantages in acquiring 3D information on an object's surface in many different applications within the past few years. For laser scanning, a highly collimated laser beam is scanned over a predefined solid angle in a regular scan pattern. While scanning, the distance to the object is measured by measuring the time of flight of the laser signal with high precision. Different commercial systems are available with a broad range of specifications. The specifications differ in measurement range, field-of-view, measurement accuracy, data acquisition speed, robustness, compactness, and transportability. The primary output delivered by a scanning laser system is a point cloud representing a sampled replica of the object's surface. The point cloud is composed usually of a very large number of points or vertices and, for most of the systems, each vertex corresponds to a single laser range measurement.

In many applications the user is not only interested in geometrical information, but also in additional information on the object's surface. Some laser sensors provide with every laser measurement also color information by converting the ambient light in the direction of the laser beam into an RGB (red-green-blue) triple. The geometrical data and the additional vertex descriptors are acquired synchronously and sequentially and the spatial resolution of the additional data can thus not be higher. In order to have texturing data with a higher resolution than the laser data, high resolution digital cameras can be used additionally. Texturing 3D models generated from laser scan data with image data is well-established and many of the 3D data processing packages provide at least some means for texturing the surface of a 3D model. However, using images of a camera without prior knowledge of its position and orientation requires, for example, manual definition of tie points in both the scan data and the image to calculate the image parameters. Integrating a high-resolution calibrated camera into a laser scanning system provides a very efficient, convenient, and powerful system for automatically generating accurately textured high-resolution 3D models.

3 *RIEGL* LMS-Z420i - SYSTEM DESCRIPTION

The hybrid sensor presented below is composed of a high-performance long-range laser scanner with a wide field-of-view and a calibrated high-resolution digital camera firmly mounted onto the scanning head of the laser scanner. As for every image taken with the camera the position and orientation of the camera is measured with high accuracy within the scanner's own coordinate system, scan data and image data can be combined in a straightforward way without the need of user interaction.

Table 1 summarizes the key specifications of the system (Riegl 2005).

Table 1. Key specifications of the system.

Hybrid Sensor	*RIEGL* LMS-Z420i with Nikon D100 [a]
Measuring range	up to 800 m at target with 80 % reflectivity
Range accuracy	10 mm (single shot)
Beam divergence	0.25 mrad
Measuring rate	8000 points/sec
Scan range	0 to 80 deg vertically, 0 to 360 deg horizontally
Scan resolution	0.004 deg
Camera chip	3008 x 2000 pixel
Camera lenses	14 mm, 20 mm, 28 mm, 35 mm, 50 mm, 85 mm, 180 mm focal length
Camera field-of-view	80 deg x 58 deg with 14 mm lens

[a] Different camera models available to match application needs.

The system is complemented by a data acquisition system based on a standard laptop. For convenience in numerous applications, both sensors, laser scanner and camera, are connected to a WLAN-Box, so the data acquisition PC can be setup remotely. Data acquisition, sensor configuration, data processing and storage are done by the companion software RiSCAN PRO. The whole system is battery powered and highly portable, but yet robust and operable in a wide range of environmental conditions.

4 DATA ACQUISITION AT PINCHANGO ALTO

The whole field-work was carried out within 5 days (see Figure 2 for a snapshot of the laser scanner at work). The remains of the eastern part of Pinchango Alto, which are in much better condition than the rest, were scanned from 47 scan positions. The high number of scan positions was necessary to guarantee both high resolution scan- and image-information on every single wall and to have only minor areas without data acquired. The whole area is covered by 60 scan positions in total. Registration of the scan data, and thus automatically of the image data, in a global coordinate system was based on scanning also cylindrical reflectors surveyed by DGPS. The internal registration accuracy of the scan data is about ± 1 cm, the accuracy of the reflector positions is about ± 5 cm, determined by the accuracy of the DGPS measurements. Already during data acquisition the data have been registered, thus immediately after completion of fieldwork a registered point cloud is available. This point cloud consists of about 270 million measurements. Additionally without the need of further registration work 420 high-resolution digital images are available too, as the internal and external orientation of camera is well-known because of an apriori calibration and the fixed mounting of the camera on the scanner.

Figure 2. Scanner at work

5 POST PROCESSING

Data can be post processed in numerous ways. The optimum choice depends strongly on the application to be covered and/or the requirements of the end-user. One of the possible output-products is a triangulated 3D-model, which can be used for automatically extracting iso lines (contour lines), profiles (cross-sections), and to perform volume calculations. Thanks to the automatic registration of the image data within the scan data, the triangulated mesh can be textured with the high-resolution image-information without user interaction. For further post processing tasks export filters available in RiSCAN PRO guarantee a seamless workflow with other software products. The point cloud and digital images may be made available inside the main CAD-Systems like AutoCAD and Microstation. Plugins available inside these CAD-Systems provide direct access to the RiSCAN PRO-project and thus to all information contained in the project such as the registration information gained during data acquisition.

5.1 *TRIANGULATED 3D-MODEL WITH TEXTURE*

To triangulate a model it is necessary to reduce the number of measurements from the total number of 270 million points to a lower level. For the eastern part of Pinchango Alto the level of detail was set to 10 cm. The model covers an area of nearly 100 m x 100 m, and consists of 1.5 million points. The triangulation of this point-cloud produces 3 million triangles. Triangulation of the point-cloud can be done by external programs and can be re-imported back to RiSCAN PRO. RiSCAN PRO offers also various ways to triangulate point-clouds. If only scan-data of a single scan-position needs to be triangulated, this can be done by a simple 2D Delauny-triangulation of the neighboring points in the horizontal- and vertical-angle grid-raster of the scan. If scan-data of a number of scan-positions should be triangulated, RiSCAN PRO offers the possibility to define the direction of 2D-Triangulation. The point-cloud can be triangulated from different sites and afterwards the overlapping meshes can be merged to a single mesh. The result is a water-proof 3D-Triangulation, which allows a straightforward calculation of volume and cross-sections (see Figure 3).

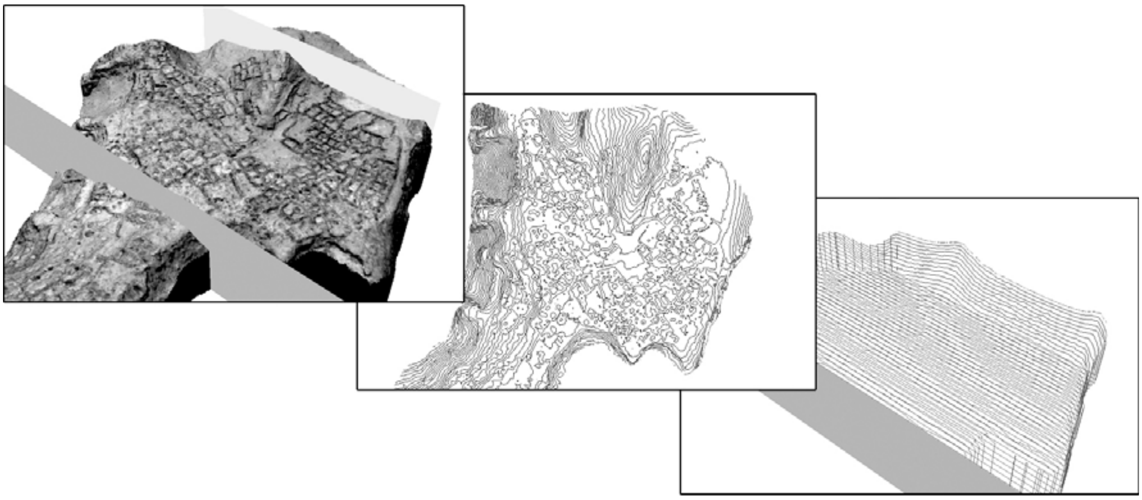

Figure 3. Triangulated 3D-model, contour-lines and profiles

Image data acquired by the hybrid sensor can be textured automatically without user interaction due to the fact, that the camera is already calibrated and the camera's position and orientation is well-known for every image (Ullrich et al. 2001, Ullrich & Schwarz & Kager 2003, Ullrich & Studnicka & Riegl 2005). The model parameters of the camera such as focal length, image center, and radial distortion parameters are determined by a calibration procedure implemented in RiSCAN PRO. Transformations of Cartesian coordinates between the camera coordinate system, the scanner coordinate system, the project coordinate system, and a geo-referenced system are formulated by 4 x 4 matrices. Table 2 and Figure 4 list the matrices used by RiSCAN PRO and give an overview on the required matrix multiplications when moving through the coordinate systems.

Table 2. Listing of the transformation matrices used for coordinate transformation.

Matrix name	Remarks
M_{SOP}	transforms from the scanner's own coordinate system at a specific scan position into the project coordinate system
M_{COP}	reflects the rigid transformation due to pan and tilt of the camera by the scan mechanism of the laser scanner with respect to a reference position (i.e., scan mechanism in position horizontal scan angle 0 deg and vertical scan angle 90 deg)
M_{Mount}	transforms from the scanner's own coordinate system into the camera's coordinate system in case the scan mechanism is in reference position
M_{POP}	transforms from the project coordinate system into the global coordinate system

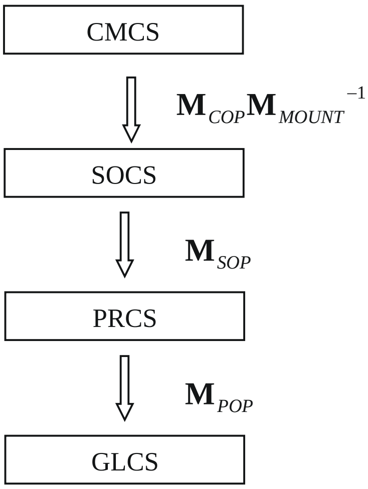

Figure 4. Coordinate transformation

As an example the left image of Figure 5 shows a part of the triangulated 3D-Model after resampling the data with 10 cm resolution. The data are color-coded according to height. The image at the center zooms in visualizing data as a point cloud with the remains of a wall represented as a textured mesh. In the right image the single wall is enlarged, generated not from the resampled but from the original high-resolution data. Texturing was performed automatically using RiSCAN PRO.

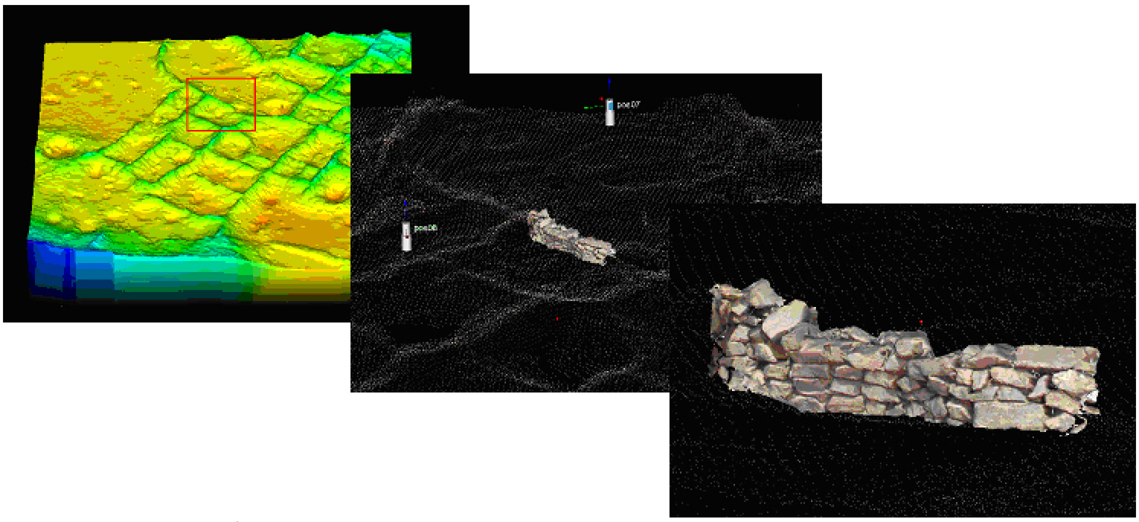

Figure 5. Texturing of the triangulated mesh. (to be reproduced in color)

6 PHIDIAS

A full exploitation of the 3D information of the data set is the mono plot procedure, possible through PHIDIAS (Effkemann 2003), a software plug-in designed for MicroStation. This evaluation system provides all the necessary photogrammetric tools for the combined evaluation of laser data and image data, while being able to display the photograph and the scanned data point cloud simultaneously, one on top of the other. The basis of a combined evaluation of both records is the perspective representation of the scan data. Therefore, users can profit from all features of a 3D - CAD system when performing an evaluation without having to renounce classical photogrammetry. The single frames can be co-oriented without consideration of the angles of convergence between the pictures, because Phidias allows to import the original RiSCAN PRO-project. All calibration data and orientation data of the images are read directly from the RiSCAN PRO project. After the definition of a drawing surface out of the scan data as plane or triangulated mesh, the object can be digitized in the high resolution photograph. The main geometrical information is extracted from the laser scandata, while for high-accuracy edge-detection and for digitizing high resolution details, which do not show up in the laser scandata, the image-information can be used. Figure 6 demonstrates how single bricks can be directly drawn in global 3D coordinates and get visible in the point cloud, in the photo image and in the CAD at once.

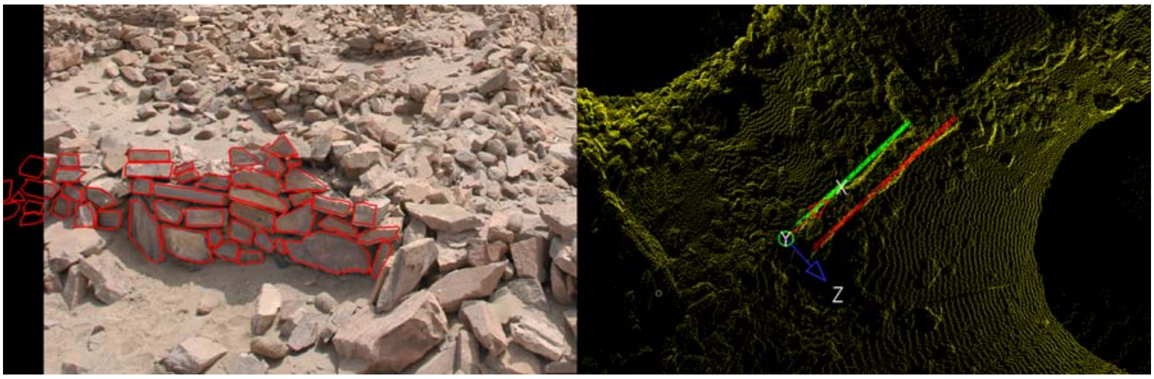

Figure 6. Mono plot procedure in PHIDIAS. (to be reproduced in color)

7 CONCLUSIONS

The characteristics of the most powerful instrument of the *RIEGL* LMS scanner series, the LMS-Z420i, are: its narrow beam divergence (0.2 mrad only), its operating range (up to 800 m), and its single-shot accuracy (10 mm, which can be improved up to 5 mm by scan sequences). As a consequence, the raw scan data provide a precious basis for different post processing activities. The time-of-flight laser measurement technique employed, allowing long range performance and reliable data acquisition even for locations difficult to access, is perfectly completed by the photogrammetric method (high pixel density, hence definition and vectorisation of edges and high accuracy of details.). Thus, the versatile hybrid instrument corresponds ideally to architectural, topographic and archaeological requirements. The high speed of operation allows a quick data acquisition, and it is therefore possible to build up an archive of historical sites and monuments for multipurpose post-processing.

REFERENCES

Effkemann, C. 2003, Integrierte Auswertung photogrammetrischer Aufnahmen und Laserscandaten mit PHIDAS, Oldenburger 3D-Tage 2003.

Riegl, Laser Measurement Systems GmbH 2005, technical data at www.riegl.com.

Ullrich, A. et al. 2001, Time-of-flight-based 3D imaging sensor with true-color channel for automated texturing, Optical 3-D Measurement Techniques V, Conference Proceedings p. 2-9, Vienna, October 1-4, 2001.

Ullrich, A. & Schwarz, R. & Kager, H. 2003, Using hybrid multi-station adjustment for an integrated camera laser-scanner system. In Optical 3-D Measurement Techniques VI, Volume 1, September 2003.

Ullrich, A. & Studnicka, N. & Riegl, J. 2005, Hybrid 3D laser sensor based on a high-performance long-range wide-field-of-view laser scanner and a calibrated high-resolution digital camera, SPIE Defense and Security Symposium, Proceedings 5412, Orlando, Florida.