UAVS FOR THE DOCUMENTATION OF ARCHAEOLOGICAL EXCAVATIONS

M. Sauerbier[a], H. Eisenbeiss[b]

[a] Institute of Historic Building Research and Conservation, ETH Zurich, Wolfgang-Pauli-Strasse 27, CH-8093 Zurich, martinsa@arch.ethz.ch
[b] Institute of Geodesy and Photogrammetry, ETH Zurich, Wolfgang-Pauli-Strasse 15, CH-8093 Zurich, ehenri@geod.baug.ethz.ch

Commission V

KEY WORDS: Archaeology, Flight Trajectory, Digital Surface Model, Orthoimage, UAV

ABSTRACT:

UAV photogrammetry experienced a growing variety of diverse applications in different scientific disciplines. Comparable early, UAVs were deployed in the Cultural Heritage and Archaeology domains, mainly for the purpose of monument, building and landscape modelling. In this paper, we will focus on the investigation of UAV application for documenting archaeological excavations. Due to the fact, that excavations are dynamic processes and therefore the objects to be acquired change significantly within few hours, UAVs can provide a suitable alternative to traditional measurement methods such as measuring tape and tachymeter in some cases. Nevertheless, the image processing steps have to be automated to a large amount as results, usually sketches, maps, orthophotos and 3D models, should be available temporally close to the related excavation event. In order to accelerate the processing workflow, an interface between the UAV ground control software and various photogrammetric software packages was developed at ETH Zurich which allows for an efficient management and transfer of orientation, trajectory and sensor data for fast project setup.
The capabilities of photogrammetric methods using UAVs as a sensor platform will be demonstrated in 3 case studies: The documentation of a large archaeological site in Bhutan, an excavation of a smaller site containing ancient tombs which include several uncovered objects in the Nasca region in Peru and the Maya site of Copán in Honduras.
The first and the third case study deal with the 3D modelling of buildings and their remains by means of photogrammetry, which means that accurate flight planning had to be applied and followed during the flights.
In the second case study, we acquired various aerial images over the excavation area Pernil Alto near Palpa in a more simple way for quick documentation of the area of interest.
In a third part, we will present our results from comparisons between the planned positions for image acquisition and the positions realized by the navigation unit during the flight for both UAV systems mentioned above. We will describe how accurate orientation data improve automated image processing if they are at hand directly after the flight and explain the workflow developed at ETH Zurich.

1. INTRODUCTION

In archaeology and cultural heritage related projects there is often the need for a rapid though accurate documentation of objects, be it during an excavation, which is a dynamic process and therefore requires fast and preferably non-immersive documentation techniques which also should be suited to cover larger areas, or be it on cultural heritage sites (e.g. monuments) which often feature high numbers of visitors and consequently only short periods available for field work. Also for these sites, non-immersive techniques are mandatory. In this paper, we present 3 different case studies where the deployment of UAVs for documentation of such sites resulted in high quality image data which serves as a basis for further processing and derivation of different products such as orthoimages, Digital Surface Models or 3D models. Furthermore, in archaeological applications it is also a prerequisite for an appropriate documentation method that traditional products like analog maps and plans can be derived from the acquired data, which using photogrammetric techniques is guaranteed.
In particular, the first case study reports about image acquisition conducted in Bhutan at ca. 3000 m a.s.l., the second one on the documentation of a Maya site in Copán, Honduras, and the third on of a fast and simple ad hoc documentation of an excavation site in Palpa, Peru. In these projects, different types of UAVs were deployed: In Honduras and Peru, we worked with a Surveycopter 1B (Aeroscout, Switzerland), driven by a two stroke engine, while in Bhutan we used a quadrocopter MD 4-100 by Microdrones provided by the company omnisight (Switzerland).
In this paper, we show based on different case studies conducted with 2 different UAVs and additional investigations using a test field and a 3rd UAV system that actual UAVs are ready for photogrammetric application also in archaeological and architectural projects. The project conditions varied from humid climate with high temperatures in Honduras, dust and heat in Peru to high altitude areas, strong temperature variations, and wind in Bhutan. Successful applications in these areas demonstrate the increased reliability of these UAV systems as compared to pilot projects conducted by our group several years ago under similar conditions in Peru (Lambers et al., 2007).

2. CASE STUDIES

2.1 Bhutan

Figure 1: View to South of the archaeological site Drapham Dzong (Bhutan).

2.1.1 Quadrotor MD4-200

For the data acquisition a mini-UAV (unmanned aerial vehicle) had to be selected, which could easily be transported from Switzerland to Bhutan and which is able to fly at an approximate height of 3000m a.s.l. This UAV system is an electrically powered quadrotor. Quadrotors are mainly light weight systems, which normally have a maximum take-off weight of up to 5kg. These systems have a size of 0.5-2m and are powered by four electrical motors. Several commercial systems are available on the market. Due to the weight limitations, these systems are highly dependent on the wind conditions. Moreover, most of the systems can only fly in manual or assisted flight modes. In the last years, several systems were upgraded by a flight control system, allowing for autonomous flights with a predefined flight path (Eisenbeiss 2009).

For our field campaign at Drapham Dzong, the quadrotor UAV md4-200 manufactured by the company microdrones (microdrones, Germany) was chosen, since a flight test at Jungfraujoch (Switzerland), at 3470 m a.s.l. in autumn 2009 had shown that the system is appropriate for flights at this height (~3000 m a.s.l.).

2.1.2 Field work

The dimensions of our area of interest were limited to 150m x 300m. The surface comprises moderate areas on the top of the hill and steep flanks, which were partly deforested (see Figure 1). The GSD of a pixel was set to 2-3cm.

For our field work in 2009 the Panasonic Lumix FX35 was used. The FX35 is a compact camera with a zoom lens. The images of this camera have a resolution of 3648*2736 pixels with a pixel size of 1.6 microns. Additionally, the camera features an integrated image stabilizer, a shutter speed of up to two milliseconds and a live-view video function.

Since no recent overview image was available, we first had to generate one in order to identify all obstacles of the flight. This image was roughly rectified using the measured ground control points (GCP). Afterwards, the rectified image was loaded into the software mdCockpit (microdrones), the image acquisition points were calculated and the waypoint attributes were set in the flight planning tool (Eisenbeiss, 2009). The main flight parameters are shown in Table 1. The autonomous flight modus was not working during data acquisition, therefore all images were finally acquired in the GPS-based assisted flight modus. During the flight, image overlap was controlled on the ground control station by the operator, using the live-view modus. Finally, we could acquire two flight lines covering the central part of the site in 25 minutes of flight time. The first flight line flown in the assisted cruising flight mode is visualized in Figure 6 (left). Additionally in this view, the start and landing trajectory is visualized.

The quadrotor used in Bhutan is highly flexible and easy to control. However, due to the weight limitations, the system is highly dependent on environmental conditions, such as wind. Particularly, it is not recommended to use the assisted flight modus with stop points. In contrast to our experiences in Bhutan, the system works probably in the autonomous flight mode (see Figure 6, right). This example shows a complete autonomous flight using the quadrotor MD4-200 in the stop mode for image acquisition. Figure 6 shows also the influence of the wind during the flight. In centenary wind direction the system hovers longer, before doing the image acquisition, while after image acquisition the system falls back in the trajectory and continues the flight. In downwind direction, this influence is negligible.

First processing results from this field campaign will be published soon in the 2009 year report of the SLSA (Swiss-Liechtenstein Foundation for Archaeological Research Abroad).

Area	H_g [m]	f [mm]	GSD [cm]	v_{UAV} (m/s)	Flight mode	Acquisition mode	Size of the area	p/q [%]
Bhutan	~120	4.4	4-5	2	Assisted	cruising	350 m x 200 m	75/75

Table 1: Main parameter of the flight planning of Drapham Dzong (Bhutan).

2.2 Copán, Honduras

Copán was a Maya city located in the northwest of Honduras near the border to Guatemala. The principal group of the city, which was documented during our field work in April 2009, has a size of 300m by 600m.

2.2.1 Copter 1B

The Copter 1B is operated by 2 people and features an extra-quick system deployment. The Copter 1B (see Eisenbeiss 2009; **Error! Reference source not found.**) has a flight control system wePilot1000 by weControl onboard. The maximum tested flight height above ground level was 2300m a.s.l. at Flüelapass (Switzerland; see Eisenbeiss, 2008). For a detailed description of the system's components we refer to (Eisenbeiss, 2004, Eisenbeiss, 2009).

The helicopter itself is powered by a 26ccm petrol engine allowing a maximum payload of 5kg with flight autonomy up to

30min. The length of the helicopter including the main rotor is approximately 2m. It is able to carry and control various digital camera sensors, such as the Canon D10, Nikon D2XS and Nikon D3X.

2.2.2 Field work

The flight planning of the UAV flights was conducted based on a digital map of the Copan site generated by Richards-Rissetto, 2009, using the 2/2.5D flight planning tool developed at ETH Zurich (Eisenbeiss, 2009 and Figure 2).

Figure 2: Visualization of the flight planning of the east and west court of Copán showing the projection centers of the individual image strips (dots) and exemplary the image coverage of view images.

The image resolution for the east and west court (Area I) was defined to 1cm, while for the main plaza (Area II) the resolution was reduced to 3cm. For the data acquisition the Nikon D2Xs 12 Megapixel still-video camera was selected, using a 35mm and a 24mm lens at 90m and 120m above ground level for the areas I and II respectively. The Nikon camera is a CMOS-sensor with 4288x2848 pixels and a pixel size of 5.5µm. The defined flight parameters are listed in Table 2. The image acquisition points were defined as cruising points, thus only the start and end point of a flight line were transferred to the flight control software. The image acquisition points between the start and end point were thus calculated through the image baseline. The areas were documented autonomous with a flight velocity of 3 and 5 m/s (Areas I and II respectively), while the image were captured in the cruising mode.
The flights at Copan were conducted in the morning for area I and in the afternoon for area II, with flight times of 12 and 10 minutes respectively.

Figure 3: Comparison of the mission integrated into the flight control system (wePilot1000) and the flight trajectory. The red line shows the planned mission, including start and home point. Black dots illustrate the acquired image positions.

2.2.3 Flight data

Due to the strong wind, which suddenly came up in the afternoon, we had to stop our flight mission for acquisition of the main plaza (Area II). Figures 4 and 5 show the influence of the wind on the observed flight control data.

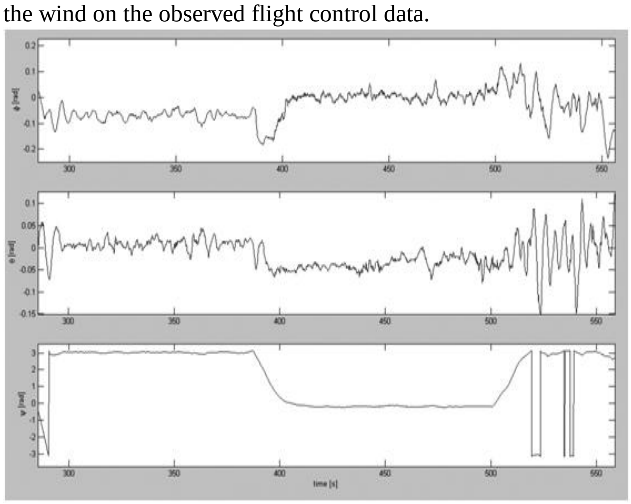

Figure 4: Orientation data of the afternoon flight. Upper graph: Φ, Middle graph: Θ, Lower graph: Ψ.

Figure 4 illustrates the orientation angles of the flight over area II. The rotation angles are plotted in relation to the flight time. The first and the second line were flown in the interval of 300s to 400s and 400s to 500s respectively. After turning into the third strip, the influence of the wind is visible in the rotation angles. The same effect could also be observed in the difference plots between the reference and the measured GPS coordinates in north and east direction, as well as the velocity values in north direction (see Figure 5).

Table 2: Main parameters of the flight planning defined for area I (East and west court) and II (Main plaza).

Area	**m_B**	**H_g [m]**	**f [mm]**	**GSD [cm]**	**v_{UAV} (m/s)**	**Flight mode**	**Acquisition mode**	**Size of the area**	**p/q [%]**
I	2500	90	35	~1	3	autonomous	cruising	200m x 200m	75/75
II	5000	120	24	3	5	autonomous	cruising	300m x 200m	75/75

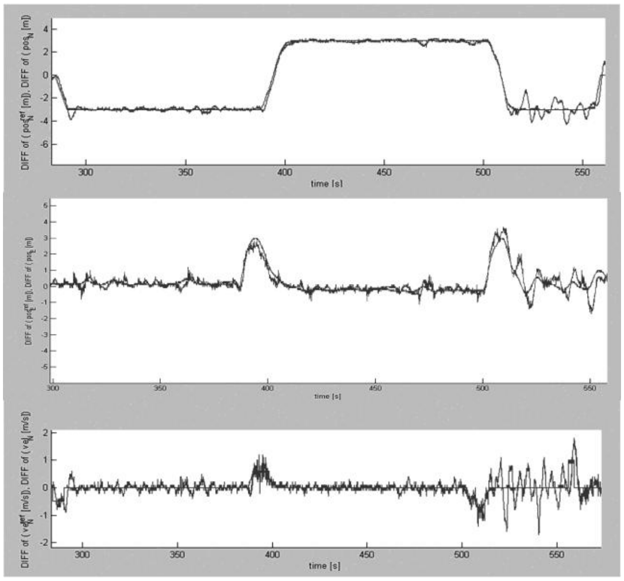

Figure 5: Differences of the reference and measured data of the afternoon flight. Upper graph: Position, north component pos_N, Middle graph: Position, east component pos_E, Lower graph: Velocity, north component v_N.

The wind gust in the afternoon had an approximate wind speed of up to 15 m/s. The evaluation of the flight trajectory (Area I, see Figure 4) shows that the planned trajectory was flown precisely in the cruising flight mode. Since the flight control system calculates the optimal route between two points during the flight, double starting and ending points of a flight line were introduced. Thus, after turning from the current line to the following line, the lines are parallel, while only the transition sector is curved.

First results of the data processing and a more comprehensive overview of the whole Copán project are given in (Remondino et al., 2009).

2.3 Pernil Alto, Peru

Pernil Alto, located near Palpa about 400 km southeast of Lima in Peru, was a longterm settlement during various cultural epochs. Recent finds were dated back to the formative period ca. 5000 B.C. stratigreaphic excavations were conducted at the site since several years by the German Archaeological Institute (DAI-KAAK, Bonn) in cooperation with the Peruvian National Institute of Culture (INC, Ica and Lima). Within the frame of field work conducted near Palpa at various sites in august 2009, we aimed for a quick ad hoc documentation of this site due to the fact that just 2 days before a mummy was found which still was in situ. The excavation area featured a size of ca. 15m x 15m.

For image acquisition, we used our mini-helicopter Surveycopter 1B, controlled by a pilot (Benedikt Imbach, company Aeroscout, Switzerland) and an operator of the ground control station. This UAV was equipped with a wePilot navigation unit and a weGCS ground station, both manufactured by the company Aeroscout.

Time restrictions only allowed for the installation of 6 control points which were measured using GPS, furthermore, a photogrammetric flight planning was not conducted beforehand. In contrast, we opted for stereoscopic overlap during image acquisition by means of optical alignment conducted by two ground based persons who gave navigation instructions to the UAV operators, namely the pilot and the operator of the ground control station. In this case, navigation was not performed autonomously but interactively in assisted mode: The involved archaeologists observed the positions of the UAV visually and led the Pilot to the desired image acquisition points for overview images. In turn, the pilot continuously communicated with the operator at the ground control station in order to receive important flight parameters such as the height over ground, battery status, engine temperature, data link conditions etc. For the acquisition of stereo pairs, the respective acquisition coordinates were calculated beforehand and then the pilot steered the UAV until the position we aimed for was reached, image acquisition was triggered manually.

Though no accurate photogrammetric flight planning was employed, we obtained images with sufficient stereoscopic overlap suitable for photogrammetric processing. One pair of images, acquired at 300 m flying height above ground, covered the whole site and control points, while 2 further images acquired at 75 m above ground mainly cover the excavation area in higher detail.

For photogrammetric processing, these 4 images were oriented together in one block, a configuration that was required because only one control point was visible in the high detail imagery.

After successful image orientation with a global accuracy of the image measurements of 1 pixel, a Digital Surface Model (DSM) with a mesh size of 2 cm was derived and subsequently, an orthoimage with a footprint of 0.8 cm was produced, both using LPS (Leica Photogrammetry Suite), compare Figure 6.

These photogrammetric products can now serve as a documentation of a certain, in this case important, state of the excavation.

The whole processing took 3 hours, while image acquisition could be finished within 4 hours including set up of the ground station, the helicopter and flight planning on site. Furthermore, it has to be noted that excavation work was minimally disturbed by this documentation method, only during the flights people had to leave the site in order to avoid occlusions in the images.

Moreover, the resolution of the acquired images is sufficient for the derivation of an archaeological plan of the excavation, or at least complementary for hand drawn sketches.

Figure 6: Orthoimage with a footprint of 0.8 cm of the excavation site. The excavation trench is clearly visible, as well as several artefacts. The visible detail allows for intra site mapping of finds down to a size in the decimetre range.

2.4 Campus Science City Zürich

2.4.1 Falcon 8

The system Falcon 8 from Ascending Technolgies is used at the Institut of Geodesy and Photogrammetry at ETH Zurich mainly for teaching and large scale projects. Currently the system is evaluated by three student thesis at our Institute. The first results from these evaluations are presented in the following.
The Falcon 8 is a multirotor system with 8 rotors. The maximum payload is limited to 500g, which allows integrating a two - axis gimbal (200g) and a still - video camera with up to 300g. The advantage of the Falcon 8 compared two systems presented above is the redundancy given through the eight motors. If one engine fails, the system is still able to proceed with the save landing maneuver. Similar to the MD4 - 200 and the Copter 1B, the system can operate autonomous, in the assisted flight mode and complete manually.

2.4.2 First results from flight data

The first results of the evaluation of the flight performance of the Falcon 8 system shows, similar to the MD4 - 200, that both systems are highly dependent on the environmental parameters, such as wind conditions. During the test at the Campus Science City Zurich, we had crosswind, which is visible in Figure 7 (especially on the top part of figure 7). Particularly, between the image acquisition points, the system is drifting in wind direction. However, the height relative to the start point is more stable as in X - and Y - direction.
Figure 8 left shows the influence of the accuracy parameter. The payload (image acquisition) is enabled, while the actual position of the system fulfils a radius of 2.5m or 1m from the planned position. Using the 2.5m accuracy, the system also acquires images with a radius larger than 2.5m, while with 1m the position is stable. Figure 8 (bottom) illustrates the differences of the stop and cruising flight mode of the Falcon 8 system. During the cruising mode the trajectory is more homogeneous (no big "jumps") across flight direction, while in the stop modus the radius to the planned position is smaller and some of the acquired positions are lying more across to the flight trajectory.

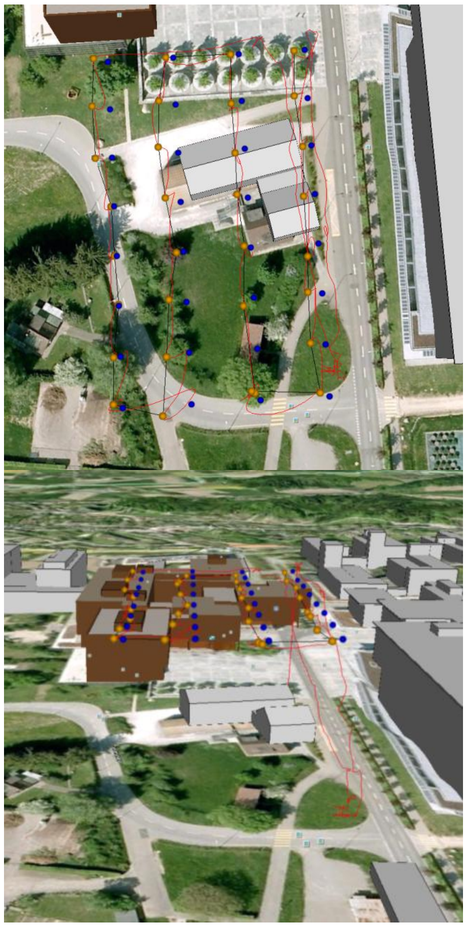

Figure 7: Flight performance of the Falcon 8 during the data acquisition at the Science City Campus Zürich visualized in Google Earth: Blue dots show the planned image acquisition points; The orange dots represent the image position obtained with the Falcon 8 system; The red line illustrates the flight trajectory. Left: Top-down view; Right: Inclined south-north view.

3. CONCLUSIONS

The experiences gathered with the above described projects and test field investigations let us come to different conclusions concerning the actual state of UAVs in terms of their applicability in photogrammetric projects, especially for the cultural heritage domain.
First of all, it can be stated that all of the investigated systems are ready for application in archaeology.
Multi-rotor systems like quad- or octocopters generally are easier to control in the manual flight mode that petrol driven engine UAVs such as the Copter 1B, which require much more experienced pilots for successful operation. Mini-helicopters furthermore are larger, which leads to more effort required for transportation and customs, though they are able to carry higher payloads and show the best flight performance in terms of accuracy. Compared to the Falcon 8 and the MD4-200 systems, the positional accuracy of the Copter 1B (1m) is significantly higher compared to 2-5m for the multi-rotor systems (Eisenbeiss et al., 2009).

Figure 8: Flight performance during the accuracy test. Black dots are the planned image positions; Left: Red/Blue dots represent the acquired position with 1m/2.5m accuracy level respectively. Right: Blue dots illustrate stop points with 5s dwelling time and green dots represents 0s dwelling time (cruising mode).

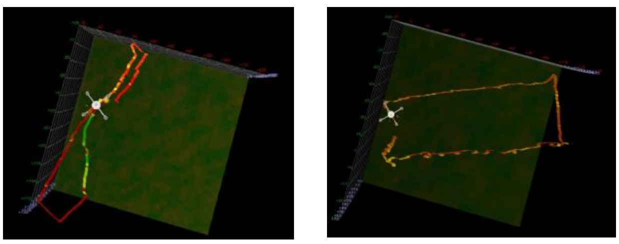

Figure 9: Left: Top-down view showing a flight line acquired over Drapham Dzong (Bhutan); Right: Topdown view of an autonomous flight over ETH forest close to Uetliberg (Zurich, Switzerland).

Additionally, it has to be noted that to our knowledge the Bhutan project was the first attempt to successfully apply a UAV at a height of ca. 3000m for a photogrammetric mission, we again refer to the SLSA year report for 2009.
In the near future, we expect UAVs being more and more applied in archaeological projects due to their capabilities regarding fast image acquisition, short interruption times for archaeological field work and non-immersive image-based measurement methods. Figure 9 shows 3D visualizations of flight paths such as here, generated using the mdCockpit software, a valuable tool for increased user friendliness of UAV systems, be it on the hardware, but also on the software side, which is an important factor in order to improve their acceptance in a broader community of potential users from archaeology and similar fields.

REFERENCES

Eisenbeiss, H., 2009. UAV Photogrammetry. PhD dissertation, Institute of Geodesy and Photogrammetry, IGP Mitteilungen Nr. 105.

Eisenbeiss, H., 2004. A mini unmanned aerial vehicle (UAV): System overview and image acquisition. International workshop on processing and visualization using high resolution imagery. Pitsanulok, Thailand, International archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVI‐5/W1: on CD‐Rom.

Eisenbeiss, H., 2008. The Autonomous Mini Helicopter: A powerful Platform for Mobile Mapping. ISPRS Congress, Beijing, China, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XXXVII. Part B1: 977‐983.

Eisenbeiss, H., Stempfhuber, W., Kolb, M., 2009. Genauigkeitsanalyse der 3D‐Trajektorie von Mini‐UAVs. 29. Wissenschaftlich‐Technische Jahrestagung der DGPF, E. Seyfert. Potsdam, Deutsche Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation (DGPF) e.V. 18: pp. 407‐417.

Lambers, K., Eisenbeiss, H., Sauerbier, M., Kupferschmidt, D., Gaisecker, T., Sotoodeh, S., Hanusch, T., 2007. Combining photogrammetry and laser scanning for the recording and modelling of the Late Intermediate Period site of Pinchango Alto, Palpa, Peru. Journal of Archaeological Science 34(10), pp. 1702-1712.

Richards‐Rissetto, H., 2009. Using Valley‐Wide GIS for Archaeological Analysis and a Google SketchUp Model of Ancient Copan. 3D Archaeology and Cultural Heritage Management in Honduras. Copan, Honduras.

Remondino, F., Gruen, A., von Schwerin, J., Eisenbeiss, H., Rizzi, A., Sauerbier, M., Richards-Rissetto, H., 2009. Multi-sensor 3D documentation of the Maya site of Copan, Proceedings of the XXIIth CIPA International Symposium, Kyoto, Japan, October 11-15.

ACKNOWLEDGEMENTS

The authors thank E. Fischer, A. Gruen, N. Tsering, F. Remondino, M. Reindel, J. Isla Cuadrado, J. von Schwerin, A.-L. Katthagen, B. Imbach, C. Eck, P. Fux, V. Sossna, E. Friedli, H. Richards-Rissotto and M. Blaha for their support during field work, preparation and processing in the presented case studies.