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3D Documentation of Archaeological Excavations Using Image-Based Point Cloud

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Dear colleagues;

We are very glad to meet you with “International Journal of Environment and Geoinformatics” special issue which is a compilation of proceedings presented in “SELÇUK INTERNATIONAL SCIENTIFIC CONFERENCE ON APPLIED SCIENCES” held on 27-30 September in Antalya/Turkey.

Besides Turkish scientists, The Selçuk ISCAS 2016 brought together Russian, Ukrainian, Kazakhstan, Azerbaijani, Persian, Algerian, Nigerian, Netherlander, Scottish, Liberian, Philippines and Czech Republican scientists. Turkey General Directorate of Land Registry and Cadastre, Republic of Turkey Ministry of Food, Agriculture and Livestock Undersecretary, International Federal of Surveyors (FIG) and International Society for Photogrammetry and Remote Sensing (ISPRS) contribute to The Selçuk ISCAS 2016 at board of director’s level.

The Selçuk International Scientific Conference on Applied Sciences (The Selçuk ISCAS 2016) held in Antalya on 27-30, September 2016. The Selçuk ISCAS 2016 is a candidate of one of the most important event in the scientific schedule and tenders a possibility for researchers and academicians who researches on applied sciences. You can find a first class programme of plenary speakers, technical sessions, exhibitions and social events in this book. You will be able to catch up with the developments in Geographical Information Sciences, Information Technology, Environmental Management and Resources, Sustainable Agriculture, Surveying, Photogrammetry and Remote Sensing, meet friends and experience the traditional and fascinating culture of TURKIYE. As an international conference in the field of geo-spatial information and remote sensing, The Selçuk ISCAS 2016 is devoted to promote the advancement of knowledge, research, development, education and training in Geographical Information Sciences, Information Technology, Environmental Management and Resources, Sustainable Agriculture, Surveying, Photogrammetry and Remote Sensing, their integration and applications, as to contribute to the well-being of humanity and the sustainability of the environment. The Conference of Selçuk ISCAS 2016 will provide us an opportunity to examine the challenges facing us, discuss how to support Future Earth with global geo-information, and formulate the future research agenda.

195 scientists from 13 countries attended to the symposium. 105 oral presentations, 40 fast oral presentations and 50 poster presentations are presented during the symposium. 145 oral and fast oral presentations take place in 24 technical sessions in two days. On the other hand, 5 invited speaker presentations held in the plenary session in the first day.

The conference is carried out with the support of the organizations as the Selçuk University, General Directorate of Land Registry and Cadastre, General Directorate Of Agricultural Reform, Turkish Cooperation and Development Agency (TIKA), International Federation of Surveyors (FIG) and International Society for Photogrammetry and Remote Sensing (ISPRS). In addition, the symposium is also supported by the commercial organizations of Paksoyteknik, Mescioğlu, Geogis, Körfez, Tümaş, 4B Ölçüm, GNSS Teknik, Arbiotek ve Anıt Hospital.

Best wishes.

Assoc. Prof. Dr. Ekrem Tuşat

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Rapid progress in digital technology enables us to create three-dimensional models using digital images. Low cost, time efficiency and accurate results of this method put to question if this technique can be an alternative to conventional documentation techniques, which generally are 2D orthogonal drawings. Accurate and detailed 3D models of archaeological features have potential for many other purposes besides geometric documentation. This study presents a recent image-based three-dimensional registration technique employed in 2013 at one of the ancient city in Turkey, using "Structure from Motion" (SfM) algorithms. A commercial software is applied to investigate whether this method can be used as an alternative to other techniques. Mesh model of the some section of the excavation section of the site were produced using point clouds were produced from the digital photographs. Accuracy assessment of the produced model was realized using the comparison of the directly measured coordinates of the ground control points with produced from model. Obtained results presented that the accuracy is around 1.3 cm.

Keywords: 3D Documentation, Photogrammetry, SfM, Excavation

Introduction

Documentation of cultural heritage is an essential and fundamental step in the multi-faceted and complex process of conservation. The geometric documentation of a monument has been defined by UNESCO as "the action of acquiring, processing, presenting and recording the necessary data for the determination of the position and the actual existing form, shape and size of a monument in the three dimensional space at a particular given moment in time. The geometric documentation records the present of the monuments, as this has been shaped in the course of time and is the necessary background for the studies of their past, as well as the studies for their future." (U.N.E.S.C.O., 1972).

The aim of archaeological excavation is to accomplish a complete picture of a site with its unique stratification. Every single object that is found has to be carefully extracted, identified, documented and evaluated (Doneus et al., 2011). The standard "dig and remove" process is essential to continue the excavation progress. When it is considered that this process causes irreversible results, it is clear that an accurate, reliable, detailed and fast documentation technique is a necessity. Image based 3D documentation techniques are quite efficient to accomplish this necessity and enable to reconstruct the removed stratification with its every components in digital environment (Doneus et al., 2005; Pollefeys et al., 2003).

Although topographical methods have become standard tools for documenting archaeological excavations, this method is generally used for 2D drawings, presented as sections, plans and elevations. It is time consuming to create a 3D model of the excavation sites using this method, even with the use of a robotic total station. Using terrestrial laser scanning (TLS) techniques offers an alternative. TLS is a very accurate method to document any kind of site, cultural or commercial (Kersten et al., 2008; Adami et al. 2007). However, instruments used for this method are very expensive and they are only purchasable for highly commercial applications. Considering the limited budgets of excavations, those tools are only used when strictly necessary to minimize the costs. Besides that, technically trained personnel is needed to collect and process the 3D data. Another alternative for fast 3D recording is the use of photogrammetric methods. Photogrammetry is applied mostly with the intention of 2D documentation and measuring in excavations. However, digital photogrammetry makes it possible to produce 3D point clouds and models of relevant areas using structure from motion (SfM) and multi-view stereo (MVS) algorithms. Parallel to the improvements in relevant computer technology, digital photogrammetry is expected to improve greatly in terms of speed and accuracy. Taking into account the usability and significantly low cost with regard to other techniques, this method is very promising to be highly preferable for 3D documentation purposes.

Applied Methodology

Structure from Motion (SfM) is a computer vision technique that detects correlating feature points – using the well-known (SIFT) algorithm or a similar one – between overlapping images and uses these points to determine the position and orientation of the camera at the moment of image acquisition (Plets et al., 2012; Ullman, 1979). After detecting a set of feature points for every photograph and matching these points throughout the multiple overlapped images, the locations of these feature points can be calculated as a sparse 3D point cloud that represents the geometry/structure of the scene in a local coordinate frame (Doneus et al., 2005; Plets et al., 2012; Fisher et al., 2005). This method has attracted great interest in recent years and many software packages – commercial as well as non-commercial – use SfM and dense stereo-reconstruction. In this study Photoscan Professional (AgiSoft LLC., 2014), developed by the Russian company Agisoft LLC., is employed. After computing the positions of the cameras using SfM algorithm, PhotoScan combines the SfM approach with a variety of dense multi-view stereo (MVS) algorithms that enable the computation of a 3D triangulated and coloured geometry of the observed area. This step generates detailed polygonal meshed models – according to the image resolution – from the previously calculated sparse point clouds (Doneus et al., 2005; Plets et al., 2012; Seitz et al., 2016). It may be necessary to edit the mesh using tools such as mesh decimation, removal of detached components, closing of holes in the mesh, etc. (AgiSoft PhotoScan, 2014). In the final step, the mesh can be textured in several ways in PhotoScan.

The created model is neither scaled nor oriented. In other words, the model is conveyed in its own local coordinate framework. At least three ground control points of which the X, Y and Z coordinates are known must be used to geo-reference the model. Ground control points can be imported into Photoscan and these reference points can be marked directly to the model or to photographs including the related ground control points. Another way to scale a model is by using a base distance, which allows an extraction of the metric information of the scaled model. Scaled but not oriented models are generally useful for single and individual objects like stones, sculptures, etc.

Case Study

The remains of the ancient Pisidian city are located on the south-facing slopes of the Taurus Mountains in the southwest of Turkey (Ağlasun/Burdur). The city is located on altitudes between 1450 and 1600m, and mostly abandoned after earthquakes in sixth and seventh centuries. The ruins of the city were covered by erosion, therefore they were preserved well against the region's rough weather condition. The archaeological remains, from the 5th century BC to the 13th century AD, are often very fragile and require appropriate documentation, conservation and management strategies (Waelkens et al., 2005; Torun et al., 2013).

The presented case study focuses on the 3D registration of the exposed remains at one of the excavated areas located on the east of the Neon Library (Figure 1) during the campaign 2013 (the "LE trenches"). The main purpose of the study was to acquire a 3D model of the trench at the end of the excavations and evaluate the technique according to parameters such as accuracy, precision and cost-efficiency. The selected trenches of the LE site exceptionally presented at the same time both some ashlar, rubble stone and brick masonry, and archaeological features of a Late Roman potter's workshop such as clay deposits and kilns (Uleners et al., 2014). Therefore it is assumed that LE trenches were appropriate site for the trial of the method.

Figure 1. Aerial view of the 2012-2013 excavation area to the East of the Neon-Library.

Data Acquisition

The excavation site that had to be documented in 3D was first covered with random ground control points before the site was photographed. After mounting the ground control points, all the points were measured by GeoMax Zoom 30 in a local coordinate system. These points are used as reference points to obtain absolute 3D geo-referencing of the model. These control points are essential in order to be able to test the accuracy of the model.

The images were shot with a Nikon D5000, a 12.9 MP digital camera. The camera was placed on a 2 to 6m long extendable pole to be able to take top-view photographs of the site as much as possible. In order to shoot top-view images, one person has to hold the pole steady and has to align the camera position parallel to the surface, whereas another person holds the remote control and shoots the images (Figure 2). Oblique images of the subject area were also shot and some important objects were photographed in more detail to make them more visible and clear in the model. All the digital images were uploaded to a computer, checked and blurred images eliminated before the images were processed. As a result, an image set was prepared which covered the subject area adequately.

Camera Calibration

Although it is not imperative to have the calibration report of the camera to create the 3D model, PhotoScan produced a user-friendly module – called Agisoft Lens – to calculate the calibration report of any digital camera.

Agisoft Lens is an automatic lens calibration software, which uses LCD screens as a calibration target. It allows an estimation of the full camera calibration matrix, including non-linear distortion coefficients.

Figure 2. Measuring with topographical tools for architectural documentation

Agisoft Lens estimates the following camera calibration parameters:

- fx, fy - focal length,
- cx, cy - principal point coordinates,
- K1, K2, K3, P1, P2 - radial and tangential distortioncoefficients, using Brown's distortion model (Agisoft Lens User Manual, 2014).

Camera calibration parameters for Nikon D5000 were calculated using Agisoft Lens before image processing. The results are shown below:

- fx = 3.1691887196458433e+003
- fy = 3.1691887196458433e+003
- cx = 2.1435000000000000e+003
- cy = 1.4235000000000000e+003
- K1 = -1.2404056909583376e-002
- K2 = -4.2838523069249736e-003
- K3 = 9.8477232864560751e-003
- P1 = -7.0101113665503275e-004
- P2 = -1.0112441422884906e-003

Image Processing

With PhotoScan, it is possible to create a 3D model automatically in three steps; i) the alignment of photographs, ii) the calculation of a dense 3D surface and, iii) the texture mapping of the model. Before the alignment of the photographs there is one pre-processing step called "masking the photographs" (Figure 3). Masks are used in PhotoScan to specify the areas on the photographs which will be evaluated and can otherwise be confusing to the program or lead to incorrect reconstruction results (AgiSoft LLC., 2014). Masking areas where “moving objects” (e.g. shadows or displaced objects) occur, where information about the texture of objects is lacking (e.g. sky and shiny objects) or where there is little variation in texture (e.g. full white objects), can be useful to produce higher quality models. Photographs that only depict zones without texture or “moving objects” can simply be omitted. The enabling, disabling or masking of (parts of) photographs can be adjusted in any stage of the process (AgiSoft PhotoScan, 2014; De Reu, J. et al., 2012).

After masking the necessary parts of the photographs, which is not an obligatory step for alignment, a first step is performed. In this step, PhotoScan uses a SfM approach to calculate relative orientation of the camera position at the moment of image acquisition and the internal camera parameters (if these parameters were not computed during the camera calibration step). The matched feature points are represented as a sparse point cloud. It is visually observed that all the photographs are aligned successfully (Figure 3). In the second step – which also calculates the colour for each model vertex and stores it as an attribute – 3D coloured geometry of the excavation site is built by using dense multi-view stereo-matching algorithms (De Reu, J. et al., 2012).

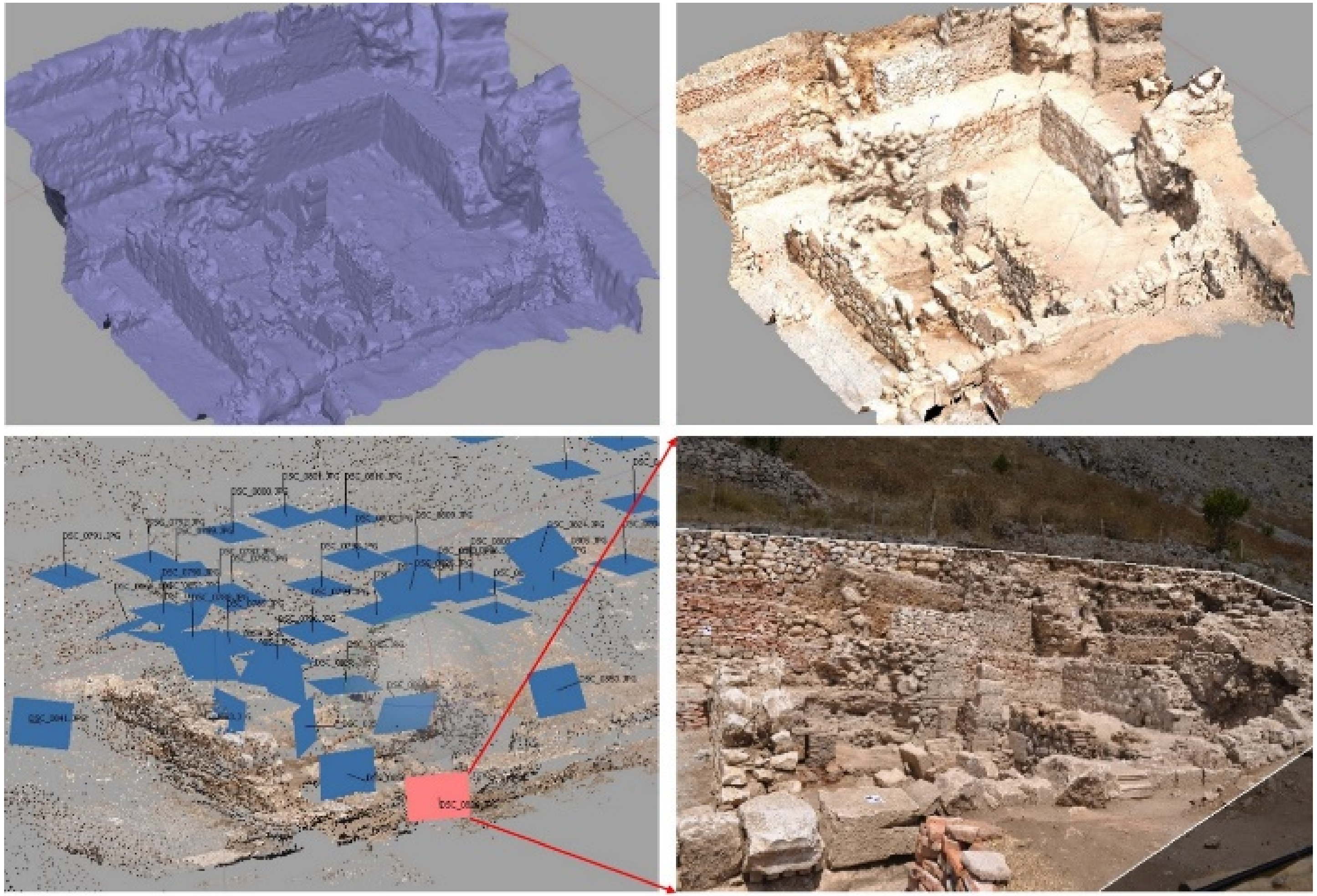

Figure 3. Top left and right: 3D mesh of the excavation site of LE (shaded and textured). Bottom left: calculated relative camera positions and spare point cloud based on matched feature points. Bottom right: The shadowed area is masked and extracted from photographs and also from image processing.

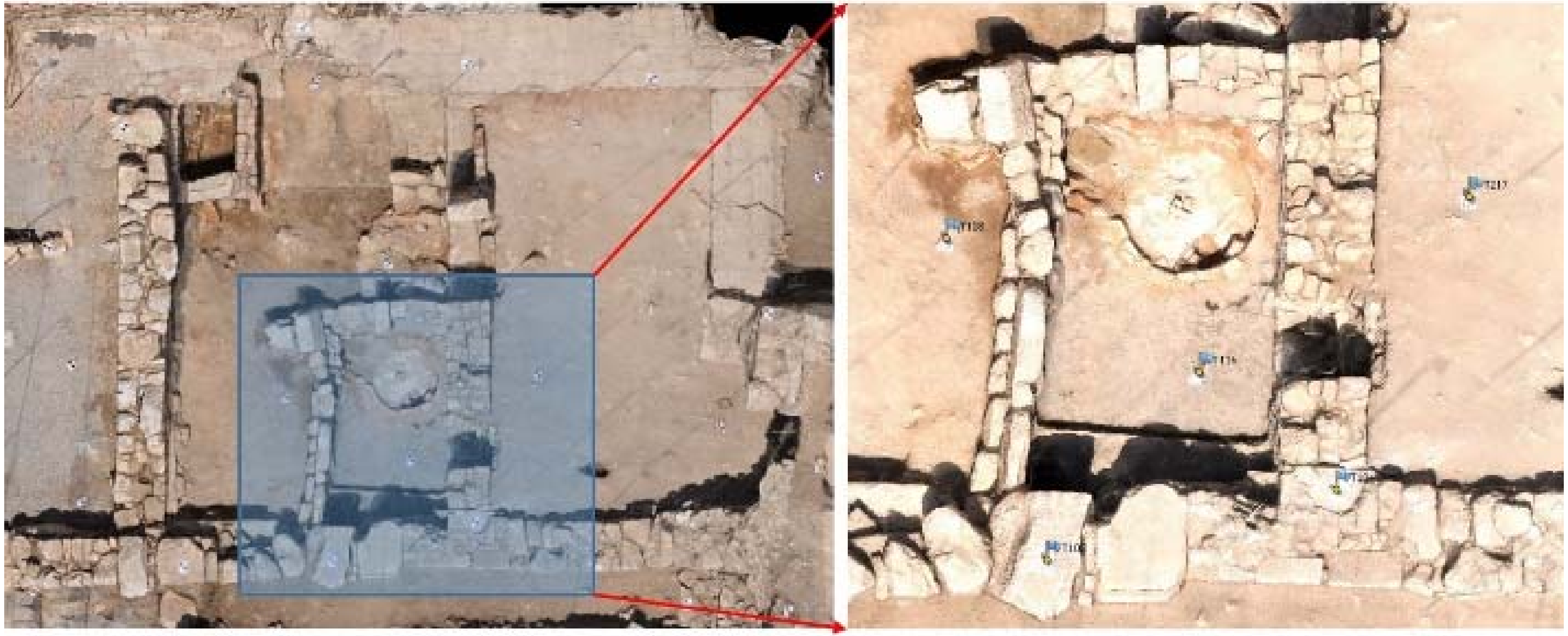

Figure 4. An ortho-image of a selected area and an image from the textured model showing the positions of GCPs

In the last step, PhotoScan can texture the model with different mapping options (AgiSoft PhotoScan, 2014). The textured model can represent the whole scene adequately if the input images are high-resolution photographs (Figure 4). The textured model is not geo-referenced. Ground control points which are covering the subject area and were already measured by a total station, are used to geo-reference the model to an absolute coordinate system and are also used to test the accuracy of the model (Figure 4).

Table 1. The accuracy of the model is calculated by a differential between Real and Estimated coordinates and shown at the bottom of the table (in meters).

GCP	RMSE(x)	RMSE(y)	RMSE(z)	Error(m)
T100	0.003	0.011	-0.007	0.013
T101	0.006	0.008	0.005	0.011
T102	-0.017	0.008	-0.003	0.019
T103	0.002	0.004	-0.003	0.005
T104	-0.001	0.003	-0.002	0.003
T105	-0.007	-0.005	0.001	0.009
T106	-0.002	-0.013	0.003	0.014
T107	0.007	-0.014	0.007	0.017
T108	0.005	0.004	-0.009	0.011
T116	0.002	0.007	-0.005	0.009
T136	-0.005	0.009	0.001	0.010
T137	-0.007	0.002	0.006	0.009
T138	-0.003	-0.014	0.004	0.015
T199	0.000	-0.012	0.008	0.014
T213	0.008	0.005	-0.013	0.017
T214	-0.006	0.005	-0.006	0.010
T215	-0.008	-0.020	0.011	0.024
T216	-0.001	-0.005	0.002	0.005
T217	0.007	0.002	0.002	0.008
T218	0.006	-0.001	0.012	0.014
T219	-0.007	-0.003	0.006	0.010
T236	0.003	-0.007	0.011	0.013
T237	0.006	0.003	0.009	0.011
T238	0.009	0.004	-0.007	0.012
T500	0.000	0.003	-0.009	0.009
T501	0.000	0.002	-0.008	0.009
T502	0.001	0.012	-0.016	0.020
Total	**0.006**	**0.008**	**0.008**	**0.013**

Figure 5. Accuracy of the model is represented as an ortho-image included error vectors.

Results

The image-based 3D documentation technique is performed at the excavation site east of Neon Library gave following results. Sixty-seven images were used to produce a 3D model of the site. Afterwards, 132179 feature points were matched.

The generated model consists of 175270 faces and 88091 vertices. The absolute geo-referencing was performed by using 27 ground control points. The accuracy of the model is represented in Table 1 and Figure 5. On the basis these results, a high-accurate and high-resolution model of the excavation site of LE is produced.

Conclusion

In this research, an image-based 3D point cloud technique – which allows accurate, fast and cost efficient 3D modelling – is used to document the 2013 campaign of LE excavation site in Sagalassos. Accuracy test of the excavation site's 3D model and resolution of the ortho-images produced from the model, proved that this technique is more efficient than the topographic and manual documentation methods. In addition to successfully documenting the final stage of the excavation sites, this method can also help building 3D surface models of all layers, and understanding the three dimensional relationships between those layers as well. Also, individual architectural structural units can be modelled with this technique to carry out anastylosis projects of destroyed/damaged architectural buildings in 2D or 3D. The visual superiority of this method will help a better interpretation as well as to create a virtual environment for experiments. The successful results obtained in this study prove that the image based 3D point cloud technique can be used for many other purposes besides geometric documentation, on smaller or larger scale. It is promising that obtained 3D documentation data will be inspiring for future studies.

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