SCIENTIFIC CULTURE, Vol. 3, No. 2, (2017), pp. 13-20
Open Access. Online & Print

DOI: 10.5281/zenodo.438183

IMAGE BASED METHODS FOR SURVEYING HERITAGE OF MASONRY ARCH BRIDGE WITH THE EXAMPLE OF DOKUZUNHAN IN KONYA, TURKEY

Cihan Altuntas, Serhan Hezer and Süleyman Kırlı

Selcuk University, Engineering Faculty, Department of Geomatics, 42075, Selcuklu, Konya, Turkey

Received: 08/11/2016
Accepted: 31/03/2017
Corresponding author: Cihan Altuntas (caltuntas@selcuk.edu.tr)

ABSTRACT

The historical structures and their heritages have been measured for documentation, touristic information and three-dimesional (3D) visualization on virtual museum. Many of the historical structures have complex details and difficult conditions to measureing of their all details. The proper measurement method should be selected for fast, lowcost and high accuracy 3D modelling of a great number of historical heritages. The image based methods of photogrammetry and dense point cloud are extensively used for three-dimensional modelling thanks to its low cost and easy implementation. In this study, historical masonry arch Dokuzunhan Bridge was measured for 3D modelling by using photogrammetry and dense point cloud methods, and the results of the methods were compared. The results show that these methods are accessible and affordable methods for 3D modelling of masonry arch bridges.

KEYWORDS: close-range photogrammetry, dense point cloud, masonry bridges, 3D modelling, image based modelling

1. INTRODUCTION

The historical heritages are cultural treasure to getting help understand the our history. Moreover, today, historical buildings are accepted as a touristic places, and the countries endeavours their restoration and publicity. Therefore 3D modelling and documentation of historical buildings are very important for their restoration and publicities. In addition, their 3D model must be created for operational analysis on it (Costa et al., 2015; Perez-Gracisa et al., 2011). A lot of historical masonry arch bridges which have different architectures and on ages have been found in Turkey. Even some of them have still been served to public usage, they are break down due to the natural or human effects. The structures and deteriorations of masonry arch bridges in Turkey had been investigated by Ural et al. (2008). It has been evaluated that the main reasons of these deteriorations are natural disasters and overload transportation.

The 3D data acquisition and object modelling have been carried out using different methods such as tacheometry, laser scanning, unmanned aerial vehicle, photogrammetry, dense point cloud etc. (Scaioni et al., 2014). But a keypoint is the selection of the most appropriate method and algorithm able to achieve the desire accuracy and completeness. Tacheometry is practical for topographic spatial data acquisition, it is not suitable to modelling for bridges. On the other hand, the unmanned aerial vehicles and laser scanning methods can be used to measuring the bridges according to its structural characteristics and scale, but they have high cost instruments. Moreover all of the details can not be visualized by laser scanner and UAV. Whereas all of the surfaces of the bridges can be imaged by the camera and 3D model can be created from the images using photogrammetric technics. In addition, dense point clouds (dense image matching) based on image processing techniques enable new possibilities in spatial data measurement from the images to visualization the objects.

The photogrammetry which has been used for many years is traditional method at image based 3D measurement with proven accuracy. Jiang et al. (2008) introduced deformation measurement and 3D modelling of steel and masonry bridges that have different architectures. Also many studies carried out that these tasks can be performed at fifty percent low cost (Jiang et al., 2008; Albert et al., 2002). The photogrammetry is the low cost 3D modelling method relation to the other measurement methods (Valenca et al., 2008).

Thanks to the great improvements in hardware and image processing algorithms, different automated procedures are nowadays available and photogrammetry-based surveying and 3D modelling can deliver comparable geometrical 3D results for many terrestrial and aerial applications. In particular photogrammetric methods for dense point clouds generation are increasingly available for professional and amateur applications with performances that cover a wide variety of applications (Remondino et al., 2013). The dense point cloud is created from stereoscopic images with applying the photogrammetric conditions (Hartley and Zissermann, 2013). The dense point cloud depicts the object geometry even so small thanks to small space between the measured points. The dense image matching and point cloud creation have been successfully used to modelling of many architectural objects (Barazzetti et al., 2010). The object at the high fifteen meters had been modelled by using the images at scale of 1/800 and then the point clouds had been computed with relative error of 1/3000. Similarly, the completion rate of the building under construction had been observed from the created dense point cloud (Brilakis et al., 2011). The images can be recorded from airborne (Gerke, 2009) and terrestrial platforms (Cavegn et al., 2015).

In this study, historical masonry arch Dokuzunhan Bridge had been measured for 3D modelling and documentation using photogrammetry and dense point cloud methods. In addition, the results of the both methods were analysed.

2. STUDY AREA: DOKUZUNHAN BRIDGE

The Dokuzunhan Bridge which is near the Caravansary called the same name is on the way from Konya to Afyonkarahisar at 24 kilometres. The people say that their name came from the stream because it was not possible to pass the other side during nine days when the weather was rainy. It does not known when it was constructed. Probably it had been build the same date with the Caravansary at 1210. It has 800 years old in this case. Today, its middle was collapsed without the remains at two sides of the stream (Figure 1).

3. DATA ACQUISITION

The photogrammetry and dense point cloud methods use images to get 3D measurement data. Thus the stereoscopic images of all details of the bridge were collected. The images were taken by the FujiFilm FinePix S4200 digital camera (4288x3216 pixel arrays). The control points were measured on the parts of the bridge to make measurements based on georeferenced coordinate frame. A theodolite

Topcon GPT-3007N was employed to this purpose, which allowed measuring control points 3-D coordinates thanks to the integrated reflectorless rangefinder. Total 38 control points were measured on surfaces of the bridge.

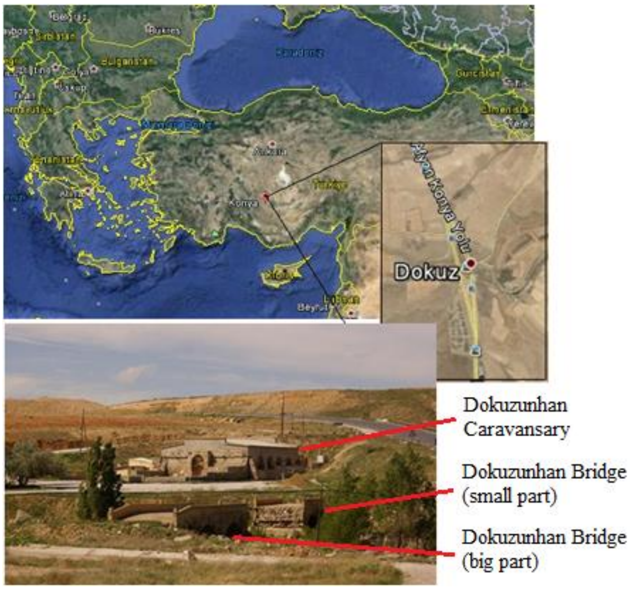


Figure 1. Dokuzunhan Bridge (Map is from Google Earth)

4. RESULTS

4.1. Photogrammetric evaluation

The basic process steps of the photogrammetry are camera calibration, image recording and 3D data acquisition. The camera should be calibrated to achieving high accuracy measurement data by the photogrammetry. The camera calibration is involve computation of inner orientation parameters that include the principal point coordinates (x_o,y_o), focal length (c) and distortion parameters (k_1,k_2,p_1,p_2). The calibration is made out with the images captured from different point of view of the special test grid (Figure 2).

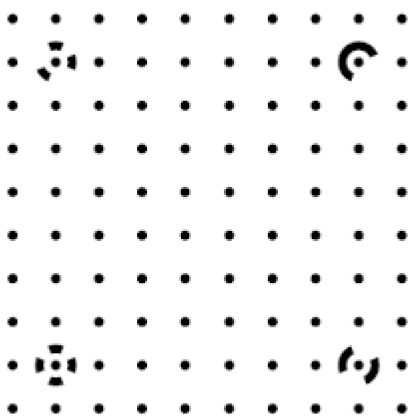


Figure 2. Photomodeler calibration grid

The twelve overlapped images of the test grid were used on the camera calibration. After the corresponding grid points from the images were matched, the calibration parameters were computed by bundle adjustment. The relationship between the image point and grid object point are expressed the collinearity conditions as similar to solving many problems in the photogrammetry.

$$x = x_o - c\frac{r_{11}(X - X_o) + r_{21}(Y - Y_o) + r_{31}(Z - Z_o)}{r_{13}(X - X_o) + r_{23}(Y - Y_o) + r_{33}(Z - Z_o)}$$
$$y = y_o - c\frac{r_{12}(X - X_o) + r_{22}(Y - Y_o) + r_{32}(Z - Z_o)}{r_{13}(X - X_o) + r_{23}(Y - Y_o) + r_{33}(Z - Z_o)}$$

Where; x,y are image coordinates, x_o,y_o are principal point coordinates, c is focal length, XYZ are object coordinates of the points and X_o,Y_o,Z_o are object coordinates of the projection center (Figure 3).

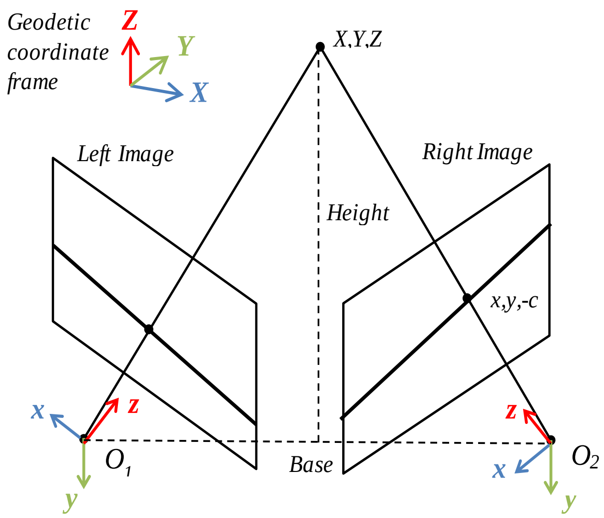


Figure 3. The collinearity condition and epipolar geometry between the stereoscopic images

The images are captured as stereoscopic from the measurement object. The three-dimensional measurement has been made from the images at 3D data acquisition step of the photogrammetry. The epipolar geometry must be realized to get three-dimensional measurement data from the stereoscopic images. After the relative orientation of the images are performed at least five corresponding points, epipolar geometry is realized for these images. The model coordinates were registered to the geodetic frame with the control points.

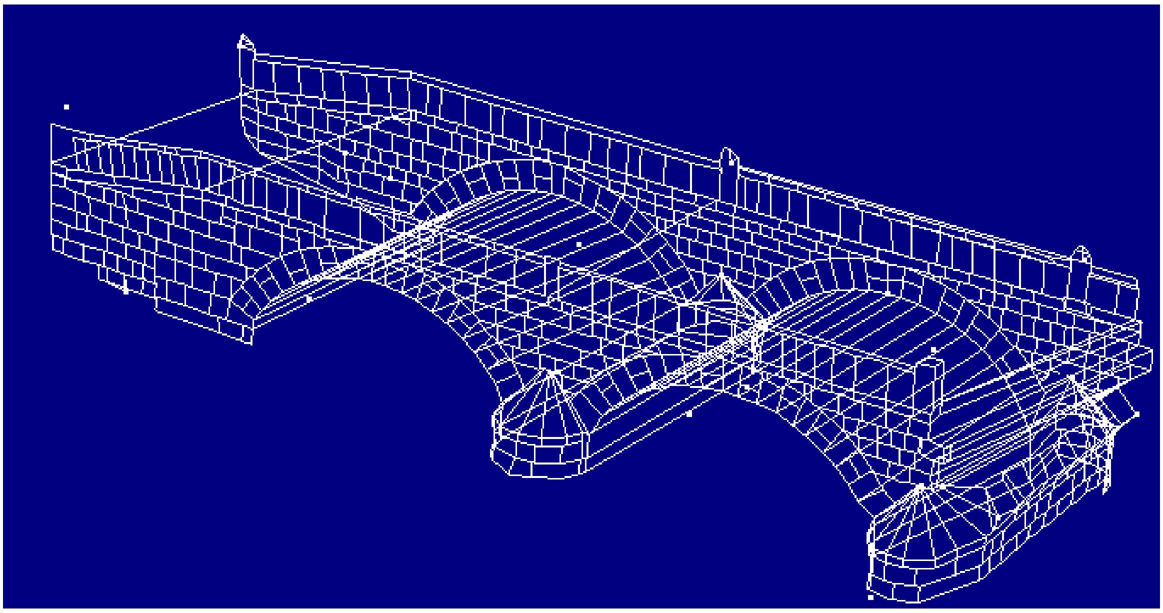
The Photomodeler software has been used for the photogrammetric evaluation (Eos Systems Inc, 2016). After the images were uploaded to the software, characteristic details of the bridge were resembled with line from the stereoscopic images. The each part of the bridge was separately evaluated, but it was registered to uniform geodetic frame thanks to control points measured based on the same geodetic frame. 12 and 18 images along with 21 and 17 control points had been used for the photogrammetric measurement of the big and small parts respectively. The bundle adjustment of the image blocks had been made root mean square error of σ_0=0.889 and σ_0=0.886 pixels (Figure 4). Then virtual model was constituted by matching texture data onto the 3D wireframe photogrammetric model (Figure 5). The most suitable image for texturing the data onto the model can be selected by filtering (Alsadik et al., 2014) or non-linear optimization (Alsadik et al., 2013). Here, the proper image was selected interactively.

4.2. Dense point cloud

The dense image matching creates point cloud from stereoscopic images automatically. This method is known as the name with structure from motion, dense image matching and image based point cloud. The main steps in creating point cloud from the images are 1) keypoint detection, 2) structure from motion and 3) point cloud creation.

At the first step, the SIFT, ASIFT, SURF and similar other operators are used to detecting the keypoints from images. These operators performed this task independently from scale, rotation and brightness of the images. Each detected keypoints are represented in 128 dimensional space vectors. The second step is detection the structure of the images with matching the similar keypoints from all the images. The image matching is referred the establishment of correspondences between keypoints extracted from two or more images and estimates the 3D coordinate via collinearity equations. Considering a simple image pair, the disparity (or parallax, i.e. the horizontal motion) is inversely proportional to the distance camera-object. The automated measurement of such disparity by establishing dense and accurate image correspondences is challenging task (Remondino et al., 2013). The matching results are in general sparse point clouds which are then used as seeds to grow additional matches. Nowadays all the algorithms focus on dense reconstructions using stereo or multi view approaches.

The actual photogrammetric softwares are capable to creating dense point cloud from stereoscopic images. In this study, dense point cloud had been generated using Agisoft Photoscan software (Agisoft, 2016). The software that has been used in many 3D modelling project so far is user friendly and high accuracy. The measurement object should be visualized near point of view angle to prevent shading effect. Therefore more images than the photogrammetry have been used on this method. All the images are simultaneously processed to get point cloud. The point clouds of the big and small parts have been achieved from 120 and 98 images respectively (Figure 6). Initially, sparse point cloud is created from the keypoints then attained the dense point cloud with computing 3D coordinates for every pixel or sub pixel spaces. The high accuracy object dimensions and cross-sections can be derived from the point cloud model (Figure 7). Furthermore the georeferencing has been carried out for dense point cloud model. Thereby, the photogrammetric measurement and dense point cloud have been formed in the same coordinate frame.



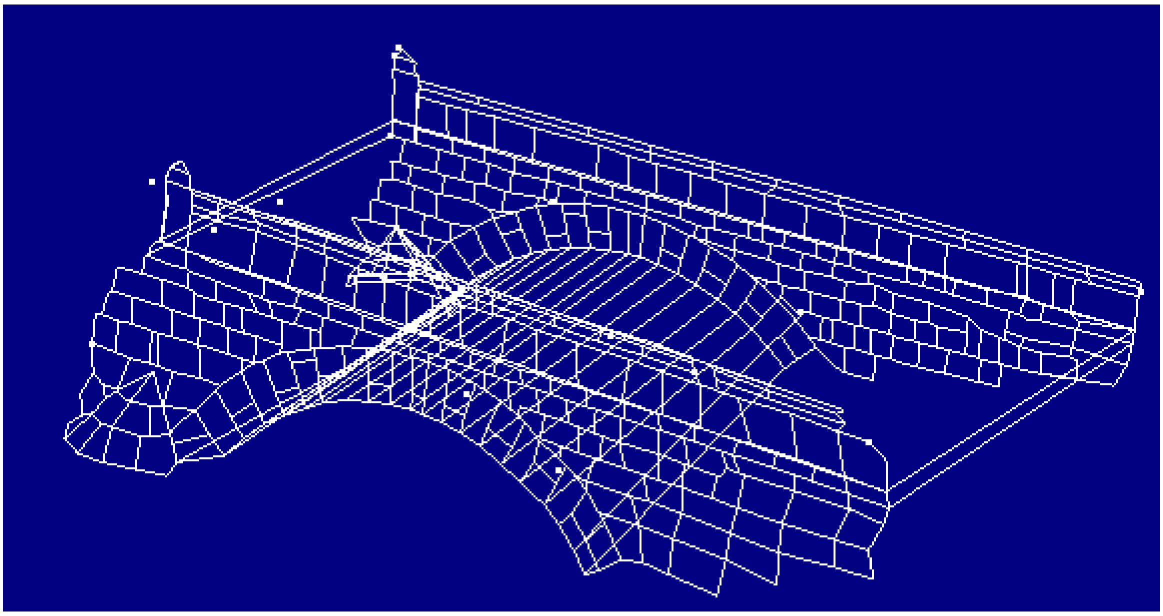


Figure 4. Wire frame visualization of big (above) and small (below) parts of Dokuzunhan Bridge

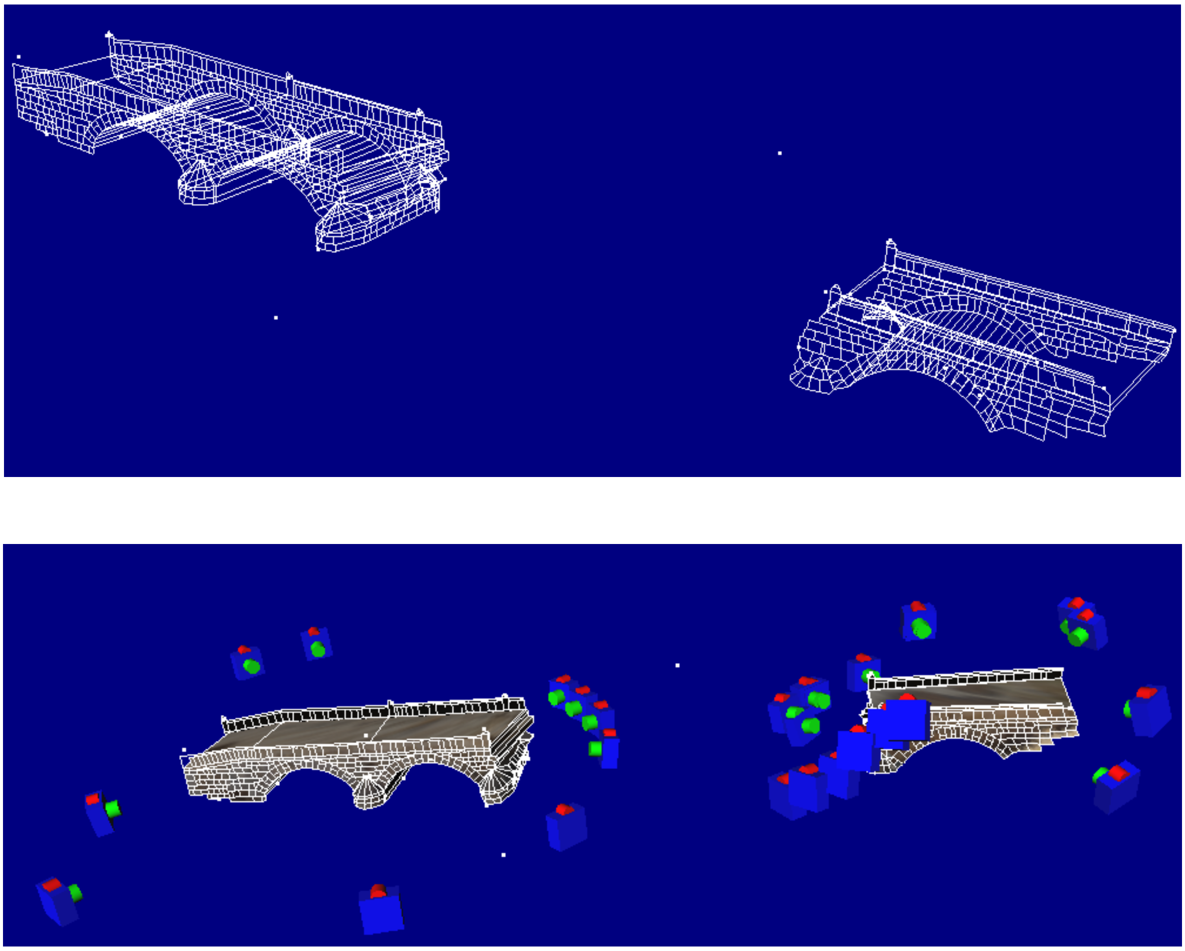


Figure 5. The combined visualization of the bridge. Wire frame visualization (above), camera stations and texture mapped 3D model (below)

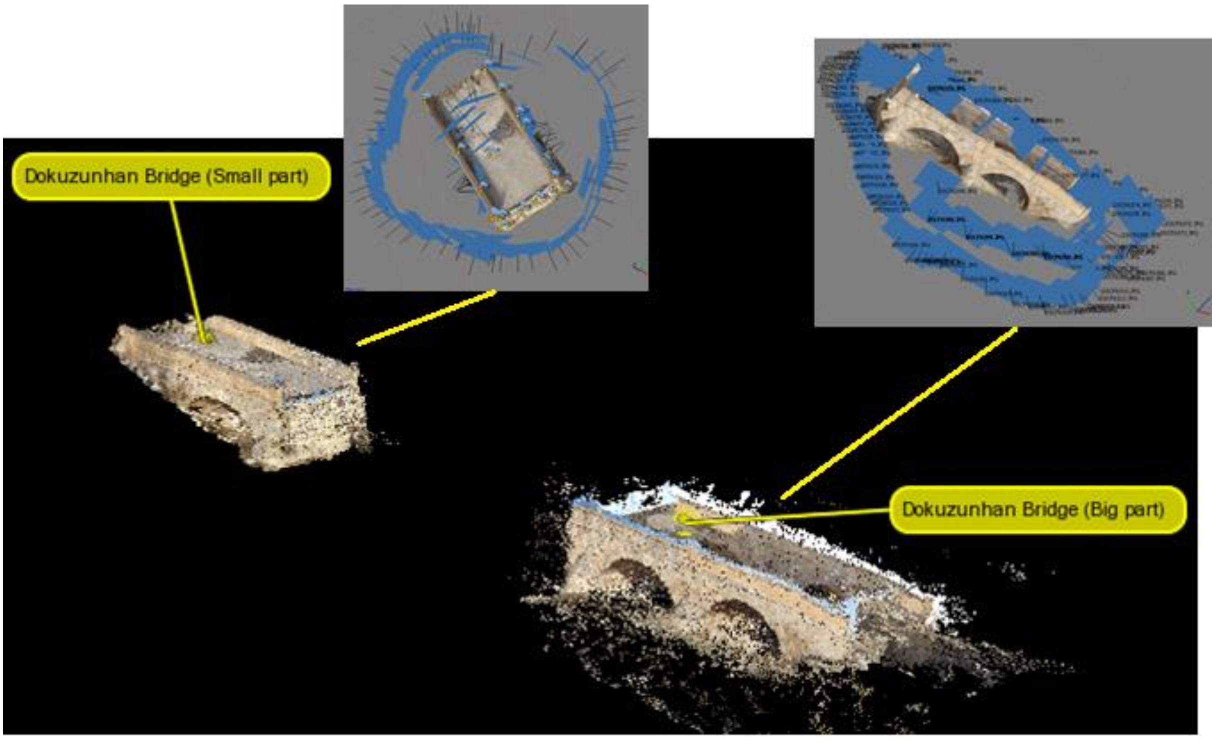


Figure 6. The imaging positions and dense point cloud models of the heritage of Dokuzunhan Bridge

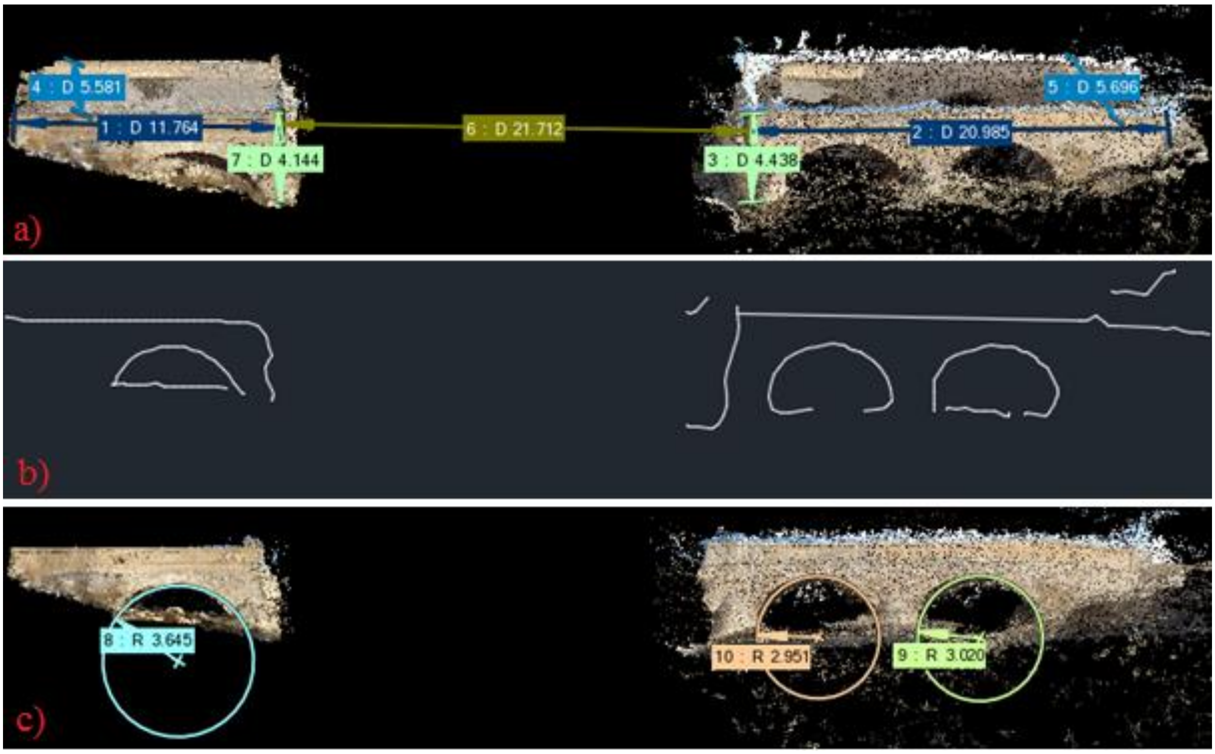


Figure 7. Documentation of Dokuzunhan Bridge. a) Dimensions, b) Cross-section, c) Radius of the circle structures (The units are meter)

5. DISCUSSION

The 3D models of the both methods were registered to georeferenced system using the same control points. The measurement error of the Total Station used to measuring control points is very low. Considering the intrinsic measurement precision of such instruments, the error related to the determination of network's stations, and the use of reflectorless mode, the precision of control points has been evaluated to be better than 5 mm in all directions

(Schofield and Breach, 2007). This precision is superior to creating high accuracy 3D object model. On the other hand the control points have uniform distribution and 38 control points which have very high number than required three were used for the georeferencing.

Both of the measurement methods exploded in this study includes image acquisition, control point measurement and 3D data derive from the images. The dense point cloud method uses more images to creating occlusion free 3D model. But more and small details can be easily measured by this method, and its measurement data resembles the object geometry close to real. The dense point cloud was created in 3 days against the 3D wireframe photogrammetric model was got in 20 days (Table 1). Furthermore, the photogrammetry needs special technical education for the evaluation. However, the dense point cloud can be achieved without any technical knowledge. After uploading the stereoscopic images and selecting the control points, all the processes proceed automatically. The task was performed with laptop computer (1.76 MHz processor and, 4GB RAM). It does not need more labour according to the photogrammetry.

The base/height ration has high effect on the accuracy of photogrammetric measurement. It should be about 1 for high accuracy result. The orientation and translation of all the stereoscopic images have computed by bundle block adjustment in photogrammetric method. By this means, all the image parameters had been computed by the same constraints. The standard deviations of the bundle block adjustment are small than one pixel (one pixel dimension is 1.43micron) for both block of the bridge. The measurement points have the root mean square error of 1.25cm and 2.37cm for the big and small parts respectively.

The camera rotation and translation parameters have been computed root mean square errors of d_{xyz}=1cm, $d_{\omega\varphi\chi}$=0.0120 degree on dense image matching. The divergences on the 38 control points had been obtained as d_{xyz}=2cm on computation of these image parameters. The both methods need computation the camera calibration parameters so as to high accuracy results. The dense image matching (dense point cloud) as distinct from the photogrammetry estimates the camera calibration parameters during the process automatically.

Table 1. The measurement results of the methods used in 3D modelling of Dokuzunhan Bridge

Methods	Data acquisition			Data processes		Measurement Results	
	Time	Image#	Control points#	Time	High labour	Points#/	Line
Photogrammetry	5 hours	30	38	20 days	Yes	4824/ very low	3441
Dense point cloud	6 hours	218	38	3 days	No	8597000/ high density	-

6. CONCLUSION

The image based modelling enables fast and low-cost creation of 3-D model for complex historical structures. The results of this study have shown that these methods can be used on 3-D measurement and documentation for historical masonry arc bridges. The photogrammetry and dense matching methods have high accuracy. The working time on the side is roughly equal for these methods, but 3D model creation from the image by the photogrammetry needs long time according to dense matching. Moreover, dense point cloud has more spatial data about the object shape. Consequently, the photogrammetry and dense matching methods are accessible and affordable methods for 3-D modelling of historical masonry arc bridges. However dense matching put oneself forward thanks to their fast and easy application without any education for 3D modelling.

REFERENCES

Agisoft Photoscan, http://www.agisoft.com/downloads/request-trial/

Albert, J., Maas, H.G., Schade, A. and Schwarz, W. (2002) Pilot Studies on Photogrammetric Bridge Deformation Measurement, Proceedings of the Second IAG Commission IV Symposium on Geodesy for Geotechnical and Structural Engineering, Berlin Germany, May 21-24, 7 pages.

Alsadik, B.S., Gerke, M. and Vosselman, G. (2013) Automated Camera Network Design for 3D Modeling of Cultural Heritage Objects, *Journal of Cultural Heritage* 14 (6), 515-526.

Alsadik, B.S., Gerke, M., Vosselman, G., Daham, A. and Jasim, L. (2014) Minimal Camera Networks for 3D Image Based Modeling of Cultural Heritage Objects, *Sensors* 14 (4), 5785-5804.

Barazetti, L., Scaioni, M. and Remondino, F. (2010) Orientation and 3D modelling from Markerless Terrestrial Images: Combining Accuracy with Automated, *The Photogrammetric Record* 25(132), 356-381.

Brilakis, I., Fathi, H. and Rashidi, A. (2011) Progressive 3D Reconstruction of Infrastructure with Videogrammetry, *Automation in Construction* 20(7), 884-895.

Cavegn, S., Haala, N., Nebiker, S., Rothermel, M. and Zwölfer, T. (2015) Evaluation of Matching Strategies for Image Based Mobile Mapping, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-3/W5, ISPRS Geospatial Week 2015, 28 Sep – 03 Oct 2015, La Grande Motte, France

Costa, C., Arêde, A., Costa, A., Caetano, E. and Cunha, A. (2015) Updating Numerical Models of Masonry Arch Bridges by Operational Modal Analysis, *International Journal of Architectural Heritage* 9(7), 760–774.

Eos Systems Inc., (2016) Photomodeler, http://www.photomodeler.com/products/modeler/default.html [Accessed on 03 Nov, 2016]

Gerke, M. (2009) Dense Matching in High Resolution Oblique Airborne Images. In: CMRT09, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., Vol. XXXVIII, Part 3/W4, Paris, pp. 77-82

Hartley, R.I. and Zisserman, A. (2013) Multiple View Geometry in Computer Vision, 2nd ed., Cambridge University Press, Cambridge, 10th printing.

Jiang, R., Jauregui, D.V. and White, K.R. (2008) Close-Range Photogrammetry Applications in Bridge Measurement: Literature Review, *Measurement* 41(8), 823-834.

Perez-Gracia, V., Capua, D.D., Caselles, O., Rial, F., Lorenzo, H., Gonzalez-Drigo, R. and Armesto, J. (2011) Characterization of a Romanesque Bridge in Galicia (Spain), *International Journal of Architectural Heritage* 5(3), 251–263.

Remondino, F., Spera, M.G., Nocerino, E., Menna, F., Nex, F. and Gonizzi-Barsanti, S. (2013) Dense Image Matching: Comparisons and Analyses, Digital Heritage International Congress (Digital Heritage), IEEE, 1: pp. 47-54

Scaioni, M., Perko, R. and Veronez, M.R. (2014) Applications of Surveying in Land Management, *Earth Science Informatics* 7 (2), 69–70

Schofield, W. and Breach, M. (2007) Engineering Surveying, 6th Edition. Butterworth-Heinemann.

Ural, A., Oruç, Ş., Doğangün, A. and Tuluk, Ö.I. (2008) Turkish Historicfal Arc Bridges and Their Deteriorations and Failures, *Engineering Failure Analysis* 15(1-2), 43-53.

Valenca, J., Julio, E. and Araujo, H. (2008) Application of Photogrammetry to Bridge Measurement, 12th International Conference on Structural Faults and Repair, Edinburgh, GB, June 10-12, pp.1-11.