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The production of line-drawing and 3D modeling of historical Mehmet Ali Bey Fountain with SFM approach

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Abstract

Historical and cultural artifacts provide information about ancient life, language, religion, literature, traditions and architecture. Documentation of cultural artifacts is of great importance in terms of protecting and transferring them to future generations. In recent years, Structure from Motion (SfM) can be used to generate dense point cloud, ortho-image, line-drawings, and 3D models in addition to the classical terrestrial photogrammetry methods. The fast documentation and archiving studies can be carried out by SfM approach using low-cost cameras with cost effective project budget. In this study, it is aimed to produce line-drawing, ortho-image, and 3D models of Mehmet Ali Bey Fountain by using SfM approach. The Mehmet Ali Bey Fountain is one of the registered historical structures in the "Monuments" class among registered immovable cultural assets throughout Turkey, located in the Abbasaga District of Besiktas/Istanbul from the Ottoman Sultan II. Mahmut period. The installation and measurement of the control points were conducted, and the image acquisition was performed with convergent image acquisition method. The 3D point cloud generation of Mehmet Ali Bey Fountain was performed after image orientation steps. The productions of 3D model, ortho-image, and line-drawing have been carried out successfully using the produced point cloud. In this study, all processes for the documentation of historical structure were carried out using "Agisoft Metashape Professional" and "Autocad" software. The analyzed measured distances between the GCPs and corresponding distances from 3D model (standard deviation of the differences is 0.5 cm) proved the success of the SfM method for documentation of registered historical artifacts and cultural heritage.

1. Introduction

The conservation of the cultural heritage is one of the most important topics for the countries since the historical artifacts and buildings are vulnerable to disasters, human actions, and tourism (Bakirman et al., 2020; Yastikli & Ozerdem, 2017). The documentation of cultural artifacts that have survived from the past to the present is a very essential task because of the high risk of deterioration of cultural heritage (Peña-Villasenín et al., 2018). Terrestrial laser scanning (TLS) is a preferred method for the documentation of cultural artifacts, but it is relatively expensive; often require time and expert knowledge for the operation (Themistocleous, 2016). Nowadays, Structure from Motion (SfM) is a popular technique for cultural heritage documentation and so, it is one of the most widely used methods in the obtaining of high resolution and high precision textured 3D point clouds as well as terrestrial laser scanners in the field of cultural heritage (Brandolini & Patrucco, 2019; Peña-Villasenín et al., 2018). The main advantages of SfM are the cost and time of execution. The SfM technique is very efficient for the conservation, monitoring, and restoration of historical and cultural artifacts because of the rapidity, easiness, completeness, and low price (Peña-Villasenín et al., 2018; To et al., 2015).

SfM method has been commonly used in cultural heritage studies for various purposes such as 3D modelling of archaeological artefacts, digitization of historical documents, monitoring of buildings, digital reconstruction of lost monuments and damaged archaeological sites, surveys of cultural and geo-heritage (Brandolini et al., 2020). To et al. (2015) proposed the archaeological documentation of the "One Pilla" pagoda located in Hanoi capital, Vietnam using

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structure from motion technique. Themistocleous (2016) employed SfM for the documentation of cultural heritage as a range imaging method to determine 3D landscape features from two dimensional (2D) image series obtained from video. Brandolini and Patrucco (2019)'s purpose is to assess a highly flexible and low-cost SfM procedure to digitize historical maps and documents using cost efficient commercial sensors. Brandolini et al. (2020) carried out SfM method in their study to document archaeological properties defined during surveys in the Sultanate of Oman. Bakirman et al. (2020) used SfM method to create 3D point cloud data of Otag-i Humayun, a historical building, with ultra-light drones (ULD) and a low-cost unmanned aerial vehicles (UAV).

In this study, an efficient approach based on SfM method was aimed to use for the producing line-drawing, ortho-image, and 3D models of Mehmet Ali Bey Fountain. For the objective of this study, installation and measurement of the ground control points were conducted, and the point cloud of Mehmet Ali Bey Fountain from the Ottoman Sultan II. Mahmut period was produced using the photographs taken with the convergent image acquisition method. The productions of 3D model, ortho-image and line-drawing have been carried out successfully using this produced point cloud. The results of this study indicate that a SfM methodology successfully supply the dense 3D point cloud, ortho-image, line-drawings, and 3D models of cultural artifacts for the documentation, restoration, and preservation studies.

2. Method

SfM is a method, using photos to compute 3D data of the targeted objects (Seitz, 2018). The SfM method uses numerous overlapping photos instead of a single stereo pair (Fig. 1). The improvements in the image-based 3D data-extraction algorithms, calibration techniques for non-metric cameras and computing hardware have contributed to the further development of SfM method (Peña-Villasenín et al., 2018). The SfM is applied in many commercial 3D modelling software such as Pix4D and Agisoft Photoscan Professional (PS) (Yastikli & Ozerdem, 2017).

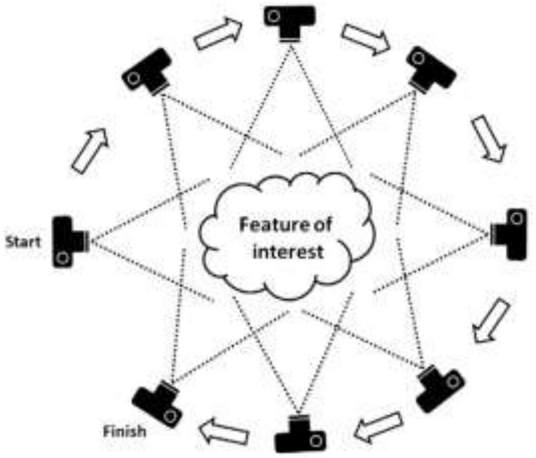

Figure 1. The SfM technique (Westoby et al., 2012)

In fact, structure from motion refers to only one stage of the SfM workflow (Smith et al., 2016). SfM technique, which is formed of a group of algorithms, is based on identifying common features and converting them into 3D information; accordingly, common features are defined and matched in all images (Lowe, 2004; Papakonstantinou et al., 2019). In other words, the epipolar geometry is estimated from 2D images using feature matching algorithms like scale-invariant feature transform (SIFT) (Brandolini & Patrucco, 2019). A sparse point cloud, unscaled 3D point cloud in arbitrary units, is generated by calculating the position of every point in 3D space, and the sparse point cloud is thickened to constitute a dense point cloud (Furukawa & Ponce, 2009; Papakonstantinou et al., 2019). The majority of the studies use Multi-View Stereo (MVS) algorithms to increase the point density after the producing sparse point cloud (Smith et al., 2016). The dense point cloud generation workflow with SfM technique is given in Fig. 2.

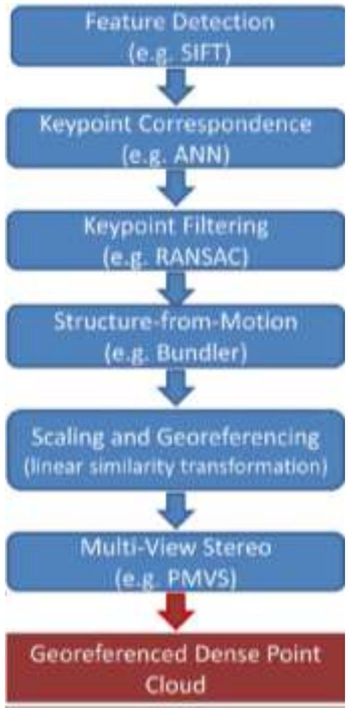

Figure 2. The workflow of the dense point cloud generation with SfM (Smith et al., 2016)

Unlike classical photogrammetry, SfM does not require the camera positions or 3D location of ground control points (GCPs) to enable scene triangulation and reconstruction (Westoby et al., 2012). In contrast, the SfM procedure use a iterative bundle adjustment based on matching features in multiple overlapping two dimensional (2D) images and estimates relative camera locations (Bakirman et al., 2020; Westoby et al., 2012). Small number of GCP is only needed in the transformation to absolute coordinate system from local image coordinate system. However, a large number of data is necessary for SfM technique to be able to reconstruct accurate dense point cloud and a good quality 3D model (Clini et al., 2016).

3. Study area and Dataset

Mehmet Ali Bey Fountain, which is one of the registered historical structures in the "Monuments" class among registered immovable cultural assets throughout Turkey, located in the Abbasaga District of Besiktas/Istanbul (Fig. 3). Mehmet Ali Bey Fountain was built in 1836 during the Ottoman Sultan II. Mahmut period by Mehmet Ali Bey. There are four different inscriptions and tugras on each side of the Mehmet Ali Bey Fountain, which is made of cut stones with a cube body.

(a)

(b)

Figure 3. The location of the fountain (City Map-2021) (a) and Mehmet Ali Bey Fountain (b)

The ground control points (GCPs) have been determined on the fountain in order to obtain the 3D model in local coordinate system. Horizontal, vertical, and diagonal distances between the GCPs were measured with a steel tape measure (see Fig 4.). A total of 181 photos were taken from near and far distances with the Canon EOS 1100D camera (see Table 1 for specifications) using the convergent image acquisition method for the production of the 3D dense point cloud using SfM technique. SfM procedure have been applied by using “Agisoft Metashape Professional” commercial software for production of the 3D dense point cloud, line-drawing, ortho-image, and 3D models of Mehmet Ali Bey Fountain.

Figure 4. The ground control points and distances between them

Table 1. Technical specifications of the used camera

Canon EOS 1100D	
Sensor Size	22.2 x 14.8 mm
Total Megapixels	12.60
Maximum Image Resolution	4272 x 2848
Weight	495 g
Dimensions	129.9 x 99.7 x 77.9
Pixel Density	3.71 MP/cm^2
Pixel Pitch	5.19 µm

4. Results

For the 3D model generation, first the camera calibration process has been performed by defining the focal length (c) and position of principal point (x_0, y_0), radial (K_1, K_2, K_3) and tangential (P_1, P_2) distortion parameters. The obtained photographs are aligned and tie points (166.612 points) have been generated to calculate the camera positions where each photograph was taken (Fig. 5). The determined ground control points are marked on all photos and the distance values between control points were identified by using the obtained measurement in the study area (Fig. 6).

Figure 5. Automatically calculated camera positions

Markers	X (m)	Y (m)	Z (m)	Accuracy (m)	Error (m)	Projections	Error (pix)
point 1	1005.850000	1000.000000	1000.000000	0.005000	0.020802	151	1.247
point 2	1000.000000	1000.000000	1000.000000	0.005000	0.024766	146	1.084
point 3	1005.850000	1000.000000	1001.700000	0.005000	0.021242	157	0.859
point 4	1000.000000	1000.000000	1001.700000	0.005000	0.022342	159	0.808
point 5	1005.850000	1005.630000	1000.000000	0.005000	0.028957	140	1.374
point 6	1005.850000	1005.630000	1001.700000	0.005000	0.023619	157	0.781
point 7	1000.000000	1005.550000	1000.000000	0.005000	0.015714	144	0.880
point 8	1000.000000	1005.550000	1001.700000	0.005000	0.020699	164	0.740

Figure 6. The point position errors of GCPs

A sparse point cloud is created using all matching points in all photos at first stage. An example of the matching points in two photos taken from different position is given Fig. 7. A dense point cloud including 49,828,870 points was obtained after the sparse point cloud generation (Fig 8a). The 3D solid model of the Mehmet Ali Bey fountain was obtained after mesh generation (Fig. 9).

Figure 7. The matching points in two photos

Figure 8. The dense point cloud of the Mehmet Ali Bey Fountain

Figure 9. The 3D model of the Mehmet Ali Bey Fountain

In order to test the accuracy of the created 3D model, the distances between the GCPs on the study area and the distances between GPSs on the 3D model were compared (see Table 2). When the difference in distances between the GCPs on the study area and the distances between GCPs on the 3D model are analyzed, the differences are between -0.5 cm and 1.3 cm, and standard deviation of the differences is 0.5 cm which is acceptable.

Table 2. The comparison of distances

Distances	Study area (m)	3D model (m)	Difference (m)	Error rate (%)
Point1_Point2	5,850	5,846	0,004	0,1
Point1_Point3	1,700	1,687	0,013	0,8
Point1_Point4	6,090	6,095	-0,005	-0,1
Point1_Point5	5,610	5,607	0,003	0,1
Point1_Point6	5,855	5,854	0,001	0,0
Point2_Point3	6,075	6,084	-0,009	-0,1
Point2_Point4	1,700	1,700	0,000	0,0
Point2_Point7	5,550	5,546	0,004	0,1
Point2_Point8	5,815	5,818	-0,003	-0,1
Point3_Point4	5,855	5,853	0,002	0,0
Point3_Point5	5,885	5,880	0,005	0,1
Point3_Point6	5,630	5,627	0,003	0,1
Point4_Point7	5,785	5,787	-0,002	0,0
Point4_Point8	5,550	5,551	-0,001	0,0
Point5_Point6	1,700	1,705	-0,005	-0,3
Point5_Point7	5,845	5,844	0,001	0,0
Point5_Point8	6,092	6,097	-0,005	-0,1
Point6_Point7	6,090	6,091	-0,001	0,0
Point6_Point8	5,860	5,859	0,001	0,0

After 3D model production, an ortho-image with a ground sample distance (GSD) of 2 mm was produced in TIFF format (Fig. 10a). All the details on one surface of the Mehmet Ali Bey fountain were drawn in stereo with anaglyph glasses, and the line-drawing of the fountain was obtained (Fig. 10b). The line-drawing of Mehmet Ali

Bey Fountain at the scale of 1/50, was obtained using "Autocad" software (see Fig. 11).

(a)

(b)

Figure 10. The ortho-image of the Mehmet Ali Bey Fountain (a) and the line-drawing overlapping the ortho-image (b)

Figure 11. The line-drawing of the Mehmet Ali Bey Fountain

5. Conclusion

In this study, line-drawing, ortho-image, and 3D models of historical Mehmet Ali Bey Fountain were successfully produced with the SfM method. When the distances between the GCPs on the study area and the distances between GCPs on the 3D model were compared, it has been seen that the standard deviation of the differences is 0.5 cm and accordingly, the error rate is within acceptable limits.

The results of this study indicate the potential of SfM method for production of the dense 3D point cloud, ortho-image, line-drawings, and 3D models of cultural artifacts for the cultural heritage. More GCPs can be selected on the fountain façade in order to obtain high accuracy, and the total stations can be used to measure more precise coordinates of GCPs. With this study, it will be possible to perform the restoration and reconstruction studies for Mehmet Ali Bey Fountain with the help of the information from the 3D model, ortho-image, and line-drawings in the possible future destruction or demolition due to natural disaster such as earthquake and flood.

Author contributions

Naci Yastikli: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft Preparation, Writing-Review and Editing, Visualization, Supervision.
Zehra Cetin: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft Preparation, Writing-Review and Editing, Visualization, Supervision
Erdal Asamaka: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft Preparation, Writing-Review and Editing, Visualization, Supervision

Conflicts of interest

The authors declare no conflicts of interest.

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