Cultural Heritage and Science

https://dergipark.org.tr/en/pub/cuhes

e-ISSN 2757-9050

3D modeling of historical theodolite with photogrammetric techniques and accuracy analysis

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Keywords
Laser Scanning
3D Modelling
Digital Preservation
Digital Cultural Heritage
Theodolite

Abstract

As historical artifacts are the common heritage of all humanity, preserving historical artifacts is very important in keeping the cultural heritage alive and passing it on to generations. Creating scale models of these works and transferring them to digital media is a useful method for reproduction and documentation. In this study, an experiment on 3D modeling of historical artifacts exhibited in the Museum of Geomatics Engineering Department of Istanbul Technical University using photogrammetry and 3D scanning methods is presented. Theodolite (19th century) in the museum were modeled in 3D using photogrammetry and 3D scanning methods, and accuracy analysis was performed. For real values, length measurements were made with calipers over the models. According to the results obtained, the accuracy is 7.3 mm photogrammetric model and 1.3 mm for the 3D scanner model.

1. Introduction

Historical artifacts are the common cultural heritage of humanity, which sheds light from the past to the future and has a great importance in transferring thousands of years of knowledge and experience. It is the common duty of all humanity to transfer historical artifacts to future generations by preserving their originality. Our country is home to many historical artifacts as an achievement of its deep-rooted history. This heritage we have is a treasure that should be transmitted to future generations in a healthy way.

Historical artifacts wear out over time, become deformed and can undergo various changes by being damaged. It is of great importance to document historical artifacts in order to monitor these changes and to carry out restoration work in accordance with the original structure during possible restoration works.

High-accuracy 3D models are needed for detailed digitization and visualization of cultural heritage such as decorative and ritual objects, historical architectural details, wall paintings, stonework art, engravings, and archaeological finds (Duran and Aydar, 2012). Laser scanning method, which provides modeling opportunities by obtaining dense point cloud, is used to a significant extent in documentation studies.

Duran and Aydar (2012) used laser scanning and photogrammetry to reconstruct an antique measuring tool called the Nippur rod. As a result, high-accuracy models were created. A digital camera and a portable laser scanner for tiny items were employed in this investigation. McCarthy (2014) used the photogrammetric approach to model tombstones from the seventeenth century. The use of unmanned aerial vehicles (UAVs) in the documenting of historical objects is demonstrated by Bakirman et al. (2020). The models created with a very light UAV and a low-cost UAV were compared in the study. Sasi and Yakar (2018) used data from terrestrial and aerial photogrammetry to create a 3D model of the Hasbey Dar'ül Huffaz building in Konya. The investigation collected data with the use of an unmanned aerial aircraft. Photogrammetry and laser scanning were used to create 3D documentation of an Early Christian obelisk in the work by Lerma and Muir (2014). Photogrammetric and laser scanning were used to create 3D representations of a medieval castle by Bolognesi et al. (2014). Yakar et al. (2010) applied photogrammetric survey for documentation purposes of Cambazlı Church and mausoleum located in Cambazlı

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Cite this article (APA);

Atik, M. E., Duran,Z., Yanalak, M., & Seker, D. Z. (2022). 3D modeling of historical theodolite with photogrammetric techniques and accuracy analysis. *Cultural Heritage and Science, 3(1), 25-29*

Research Article

Received: 30/05/2022; Accepted: 08/07/2022

village of Silifke district of Mersin province. 3D model of Ivriz relief, which is located on Mount Aydos in the village of Ivriz, is generated using a photogrammetric technique by Sanlıoglu et al. (2013). In another study by Zeybek and Kaya (2020), damage analysis was carried out with the help of the photogrammetric technique.

In this study, the Theodolite instrument belonging to the 19th century, which is exhibited in the Historical Measuring Instruments Museum of Istanbul Technical University Geomatics Engineering Department, was modeled using photogrammetry and 3D scanner technique. Accuracies of the models were compared using measurements made with a caliper.

2. Material and Method

2.1. Camera

Nikon D800 device was used for photogrammetric 3D modeling of historical measuring instruments in the scope of the study. The sensor specifications of the camera are shown in Table 1.

Table 1. Nikon D800 Sensor Specifications.

Property	Explanation
Sensor type	CMOS
Effective pixel	36MP
Maximum resolution	7360X4912
Sensor format	Full Frame
Sensor size	39x24 mm
Minimum ISO	100
Maximum ISO	6400

2.2. Structure From Motion (SFM)

Photogrammetry is used for 3D reconstruction of objects from analog or digital images. In the current situation, 3D models can be created with terrestrial photogrammetry using photographs obtained from digital cameras and special software (Duran et al., 2017). The software used in the study works in accordance with Structure-from-Motion (SfM). SFM calculates the 3D coordinates of objects using conjugate points in two images (Duran et al., 2021). SFM automatically calculates camera positions and orientations (Fig. 1). An automatically extracted feature data from a set of images is simultaneously decoded using a highly redundant, iterative procedure of beam compensation (Westoby et al., 2012).

2.3. Handheld Scanner

Contactless 3D scanners do not require physical contact with the object. They can scan objects with active or passive techniques. As a result, reverse engineering allows a precise point cloud to be produced for tasks such as virtual assembly, engineering analysis or rapid prototyping (Ebrahim, 2015). In this study, Scantech iReal 2E device was used to produce 3D models of historical measuring instruments (Fig. 2).

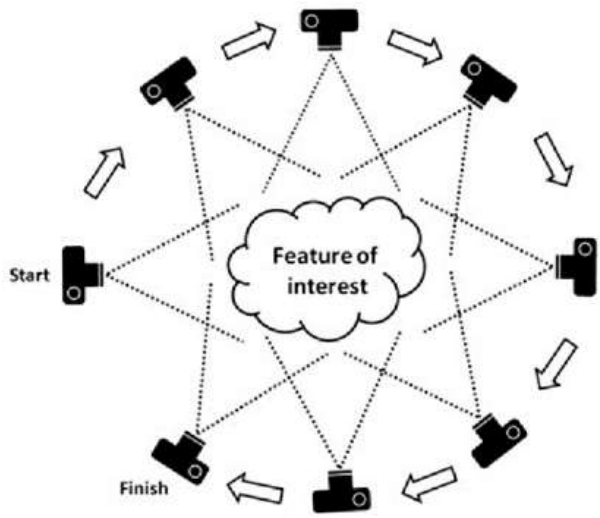

Figure 1. Structure-from-Motion (SfM) (Westoby et al., 2012).

Figure 2. 3D scanner used in the study

An alternative to conventional laser scanners is structured light scanners. Structured Light is a method used for 3D reconstruction of surfaces, working with a method similar to triangulation (Schmalz et al., 2012). The triangulation principle, which can be accepted as the working principle of the structured light (Atik and Duran, 2021), is shown in Fig. 3. The 3D coordinates of an object point can be reconstructed in a calibrated system. In structured light scanners, one or more light patterns are projected onto a scene and observed by a camera. When light hits the surface of the artifact, it is distorted by the specific geometry available captured by a camera (Gebler et al., 2021). Captured images are then analyzed, allowing the depth and surface information of objects to be calculated based on the distortion that has occurred. In this way, the geometry of the artifact can be estimated, and thus a 3D model can be reconstructed (Xin et al., 2008).

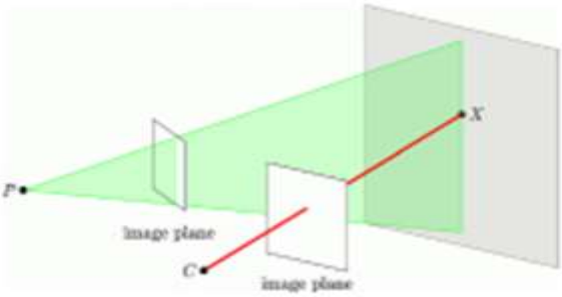

Figure 3. Principe of triangulation (Schmalz et al., 2012).

2.4. Theodolite

Theodolites are precision optical instruments capable of measuring horizontal and vertical angles, distances and dimensions between points, lines and objects in open areas or fields. The Theodolite tool appeared on the stage of history for the first time in 1571, when Leonard Digges defined it as "Theodolitus" in his book "Pantometria". The theodolite used in our study is dated the 19th century and was produced by the Sartorius firm (Fig. 4).

Figure 4. Historical theodolite

3. Experiment

Terrestrial photogrammetry and 3D scanning technologies were used in the 3D modeling of historical measuring instruments. First, the camera used in the modeling process was calibrated. With the help of the total station, a local coordinate system was established for the test area of the instruments. Within the scope of this study, Nikon D800 camera was used and calibration process was performed in Agisoft Metashape program. For the calibration process, 13 photos of the calibration board provided by the software were taken from different angles, and these photos were transferred to the software and the camera was calibrated.

While establishing the local coordinate system, firstly, two polygon points were established in order to calculate the forward estimation. Horizontal open, vertical angle and distance measurements were carried out from the points to the points in the test area with the help of a total station. A total of approximately 25 control points have been established on this test point (Fig. 5).

Figure 5. Image capturing platform.

Photographs of the objects placed in the text area where the local coordinate system was created were taken. On average, 80 photos were taken per model. After the photo shooting process was completed, the images were transferred to the software. Sparse point cloud, dense point cloud and mesh model were produced, respectively. Then the mesh model was textured.

In order for the scanner to detect the object more easily, the object was raised from the ground and objects of different colors and textures were placed around it. For scanning, it was rotated 360 degrees around the object and it was aimed to detect fine details. After the scanning process was completed, it was started to prepare the 3D object with iReal 3D software. Dense point cloud and mesh model were created, respectively, through the software.

4. Results

As a result of photogrammetric processes and 3D scanning, solid models of historical theodolite were produced (Fig. 6 and Fig. 7). Then, the lengths measured with the caliper on the real object were also measured on the models. According to the results obtained, the root mean square error (RMSE) for the photogrammetric model is 7.3 mm and for 3D scanning model is 1.3 mm. The results are presented in Table 2.

Figure 6. Photogrammetric model of the theodolite

Figure 7. 3D scanning model of the theodolite.

Table 2. Length measured using caliper from model and real object. The values are given as mm

Length	Reference	Photogrammetry	3D Scanning
1	10.20	9.65	10.10
2	18.10	16.90	17.10
3	20.95	19.40	19.70
4	20.90	19.75	19.60
5	22.80	21.30	21.00
6	39.70	38.10	37.10
7	92.70	76.80	92.90
8	116.70	101.75	117.90
9	21.50	17.50	21.40
10	40.80	35.75	41.60
RMSE		7.3	1.3

5. Discussion

In visual interpretation, it is seen that the light brightness in the model causes distortions in the pattern of the model. The inscriptions on the instrument can be seen clearly on the models. To evaluate the accuracy of the models created using two distinct procedures, length measurements were taken using a caliper with a 1/100 mm precision and the object's points were calculated. On the model, the lengths between the identical points were measured, and error estimations were done using the caliper size as a reference.

3D scanning method gives more accurate results than the photogrammetric method. During scanning, it was observed that reflective and transparent objects such as mirrors and glass were difficult to detect by the scanner. Attention should be paid to the light angle and image clarity during photo shoots. Images that are not obtained under suitable conditions cause distortions in the photogrammetric model. Among the reasons why the photogrammetric method gives less accuracy, errors that may arise from the operator, errors caused by the transparent and reflective structure of some objects, and errors caused by external factors such as the amount of ambient light.

6. Conclusion

In this study, historical theodolite from the 19th century on display at the Historical Measuring Instruments Museum of Istanbul Technical University Geomatics Engineering Department were modeled by photogrammetry and 3D scanning method.

Photogrammetric techniques successfully present historical artifacts in the digital environment. Because of the coordinated and scaled models, the reproduction and repair of the instruments is possible. Several models can be scanned and used in the future. As a result, a virtual museum may be built. Many individuals may view the models over the internet thanks to virtual museums.

Acknowledgement

The study was supported by Istanbul Technical University Scientific Research Office (BAP) with the project number MGA-2021-43139.

Author contributions

Muhammed Enes Atik: Original draft preparation, Methodology, Original draft preparation, Extended analysis.
Zaide Duran: Investigation, Funding, Writing-Reviewing and Editing.
Mustafa Yanalak: Conceptualization, Supervision, Visualization.
Dursun Zafer Seker: Data curation, Writing-Reviewing and Editing, Validation.

Conflicts of interest

There is no conflict of interest between the authors.

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