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3D modelling of cultural heritage with point cloud generation by integrating UAV and terrestrial photogrammetry techniques

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Abstract

In today's context, the preservation of cultural heritage, its transmission to future generations, and the archival in the digital environment for architectural restoration have gained momentum beyond traditional methods. In architectural restoration, surveying involves scaling and documenting the current state of structures, examining the urban design, and providing a basis for restoration projects. Photogrammetry is a commonly used method in documenting cultural heritage. In this study, UAV (Unmanned Aerial Vehicle) and terrestrial photogrammetry methods were integrated for the purpose of creating a 3D point cloud and modelling a historical building in the Yıldız Technical University Davutpaşa Campus. The building, formerly the Mızraklı Süvari Alayı Koğuşu belonging to the military, has been restored as a guesthouse. In this context, for the application of terrestrial photogrammetry in the study, 11 survey marks were established surrounding the guesthouse facades. Additionally, 205 control points were set for the facades, and a geodetic network was established in the study area for the geodetic measurements of control points. Subsequently, 554 photos were taken for the facades with an overlap ratio of 80%. For roof modelling, aerial photogrammetry was used, and 33 roof images were obtained using DJI Zenmuse P1 as the UAV. All acquired data were processed in Agisoft Metashape software to generate a 3D model. The accuracy of the results was evaluated by comparing them with ground truth values, assessing the usability of the methods in surveying studies.

Introduction

The structures that emerge as cultural heritage are treasures passed down to us from the past to the present. Our country has hosted various cultures and civilizations for centuries. These civilizations have left many legacies, and it is our duty to preserve and sustain these legacies. However, these structures are under threat due to various natural or human-made reasons. Preserving cultural heritage is not just about preserving the past; it is also crucial for future generations to access it. Therefore, the first and most important step is the documentation of these artifacts [1]. With the help of these documents, any restoration or similar work on cultural and historical structures can be supported [4]. To carry out restoration projects, it is essential to determine the current state of the structure and prepare surveys. Surveying is the collection of technical measurements that provide a reference for correcting an architectural structure if it is damaged for any reason [2]. Initially measured using classical methods, surveys have become more common over time, especially with photogrammetric methods, as different disciplines have come into play [4]. With recent developments, the integration of photogrammetry with unmanned aerial vehicles (UAVs) has made it easier to model objects in 3D quickly and economically, even in challenging and inaccessible areas, using photographs obtained with UAVs [5-6-7]. While terrestrial photogrammetry provides more detailed, precise, and close-up opportunities for indoor spaces, aerial photogrammetry offers an economical and fast modeling solution in difficult terrain conditions, large-scale archaeological areas, and areas at heights unreachable by terrestrial photogrammetry. The choice of the appropriate technique depends on project requirements, scale, and budget.

In this study, UAV and Terrestrial Photogrammetry methods were integrated to create a 3D point cloud and model of a historical building. The accuracy of the results was evaluated by comparing them with ground truth values, assessing the usability of the applied methods in surveying studies.

Material and Method

The modeled structure is a historical building located in the Yıldız Technical University Davutpaşa campus, formerly known as Mızraklı Süvari Alayı Koğuşu belonging to the military, now restored as a guesthouse (Figure 1-a). The building consists of 12 facades and a roof. It features a concave architecture with an entrance section made of glass and other sections made of stone (Figure 1-b). Around the building, 11 survey marks were established using a Topcon HiPer SR GPS device, allowing at least two network points of control points to be observable, and a geodetic network was established. For terrestrial photogrammetry measurements, 205 control points were placed on the facades in a homogeneous distribution. The x, y, and z coordinates of the control points were acquired using a TOPCON GPT-3500 total station (Figure 1-c). Subsequently, 554 photos were taken for modeling with an overlap ratio of 80%. For aerial photogrammetry, 33 roof images were obtained by flying at an altitude of 80 m with a DJI Zenmuse P1 model drone (Figure 1-c). All acquired data were processed using Agisoft Metashape software to create a 3D point cloud and model. Agisoft Metashape is a modeling software based on the Structure from Motion (SfM) technique [5]. Initially, the captured photos were aligned, resulting in tie points, i.e., a sparse point cloud. After creating the sparse point cloud, the coordinates of the object and particular points measured in the field with a total station were transferred to the system. These transferred coordinates were individually measured in each photograph, and adjustment was performed.

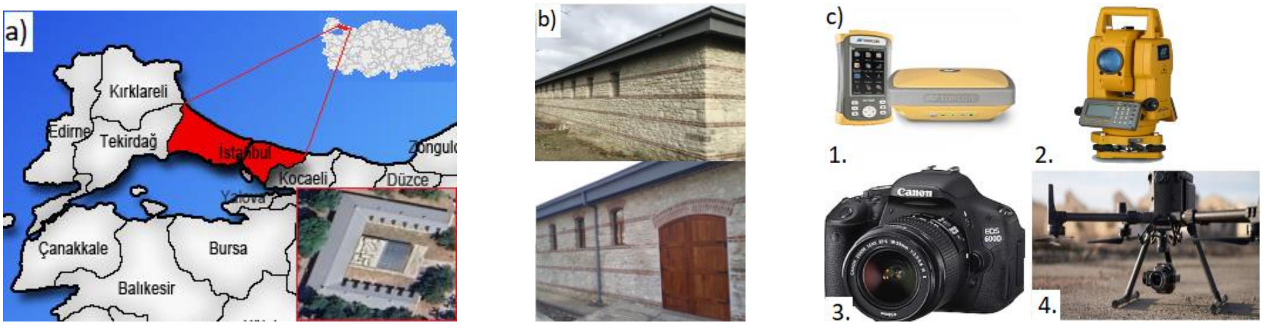

Figure 1. Location of the Historical Building (a) Guest house (b) Used Equipments (c) Topcon HiPer SR (1) TOPKON GPT-3500 (2) Canon EOS 600D Camera (3) DJI Zenmuse P1(4)

After scaling based on the measured points in this system, the metashape workflow was continued and a high-density point cloud was produced (Figure 2). Care was taken to keep the coordinate errors in the produced point cloud below 2 cm, that is, 0.5 pixels. Unnecessary points around the model were cleaned and build texture was performed.

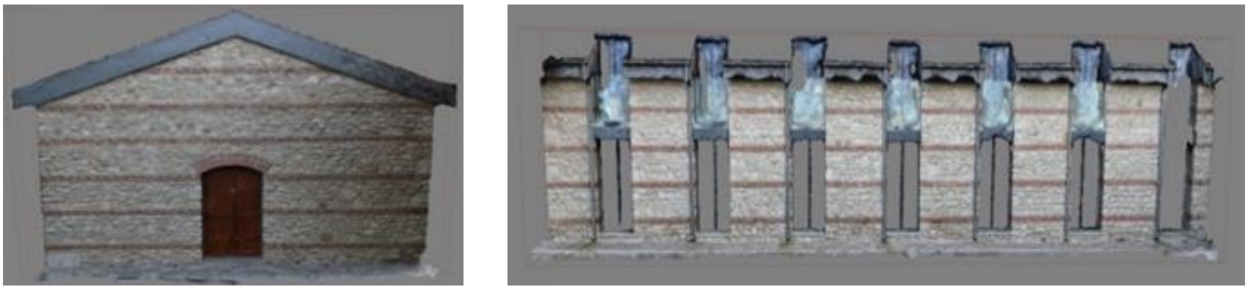

Figure 2. The point cloud models of two different facades of the guesthouse

By integrating UAV and Terrestrial Photogrammetry techniques, the 3D point cloud and model of the cultural heritage have been generated (Figure 3). The relative accuracy of the produced model is achieved at 2 cm. When compared to ground measurements, the planimetric accuracy is calculated around 3 cm.

Figure 3. Merged terrestrial and aerial photogrammetry models

Due to tall trees surrounding the stone structure and covering its top, significant problems have been encountered in some facades and corners (Figure 4). To address this, the acquisition distance was reduced, and the number of photographs was increased. However, the decrease in acquisition distance resulted in missing point cloud data in the roofed part of the building (Figure 4a). Additionally, since the entrance facades and balcony sections of the structure are made of glass, scattering has occurred in the point clouds (Figure 4b).

Figure 4. Point cloud loss due to trees and glass-fronted facades

Conclusion

In this study, the 3D modeling of historical artifacts for survey and restoration purposes was aimed. For this purpose, facade photographs were taken with a terrestrial camera and roof photographs were taken with a UAV, resulting in the generation of a point cloud and the creation of a 3D model. The accuracy of the model is 2 cm, and the absolute accuracy obtained with terrestrial controls is around 3 cm. To achieve this accuracy, the maximum photographing distance was calculated as 20 m. However, when obstacles such as trees and generators were encountered on the facades, the photographing distance was reduced, leading to an increase in the number of photographs. Similar calculations and estimations for achieving the desired accuracy should be made during UAV acquisition, and the flight height should be estimated in advance. Point cloud losses occurred in the models due to scattering on smooth and glass surfaces. Similarly, areas where point clouds could not be generated on the facades were observed due to obstacles such as trees, generator boxes, etc.

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