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Adaptation analysis of produced 3D models from UAV-SLAM and UAV-TLS data combinations

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Abstract

Photogrammetric techniques are widely used to represent the characteristics of historical buildings in the digital environment in the closest way to reality. Terrestrial photogrammetric methods have needed different alternatives in recent years to produce 3D models that offer high reality. In recent years, producing point data with the Terrestrial Laser Scanner (TLS), Unmanned Aerial Vehicles (UAV) images, and alternative methods such as the Simultaneous Localization and Mapping (SLAM) algorithm has become popular. Aligning point data from different approaches and making 3D models create new problems. Primarily, it is necessary to investigate the operations performed manually by the operator over time. Also, it is needed to explore the integration of automatic algorithms such as Iterative Closest Point (ICP) in terms of accuracy. In this research, point data of the Dokuz Historical Bridge was produced using different aligning techniques manually and automatically with the ICP algorithm. The assessment has been done from the results of combined point data over time and accuracy. In both UAV-TLS and UAV-SLAM aligning procedures, spatial accuracy was determined as 2.8cm and 4cm, respectively, in the operations performed by the operator and 46cm and 12cm in the procedures performed automatically by ICP. As a result, it was determined that the operators combined produced better findings, especially in research including coordinate transform.

1. Introduction

Cultural heritages contain the experiences and traditions of the society in the past years and play a leading role in transferring this structure to future generations [1]. For this reason, cultural heritages constitute the identity structure of the society [2]. An important part of cultural heritage is historical artifacts. Madrasahs, mosques, churches, statues, bridges, etc. are shown as examples of historical works [3].

Among the photogrammetric methods, the most preferred terrestrial photogrammetry technique in the documentation of architectural works, regardless of the size of the object, generating 3D models and point data using images obtained from different camera angles from the earth [4], has been used as a complementary method in other research subjects in recent years with the developing technology [1,2,4]. Terrestrial Laser Scanners (TLS) are used more frequently in 3D modeling of historical buildings and in obtaining point clouds [5]. In addition to TLS, the Simultaneous Localization and Mapping-SLAM algorithm, another technique to be fast, practical, and will allow robotic mapping in the future, can also be used in the interiors of historical buildings, etc. It is known to be used for studies [6]. It is also known in the literature that in almost all photogrammetric methods, it is difficult to obtain data on the upper parts of the structures, such as the roof, and to determine the details of the structure [7,8]. Using the mentioned techniques, studies are carried out with Unmanned Aerial Vehicles (UAV) integrated systems, and the results obtained in these studies provide final products with high location-based accuracy [9].

Today, UAVs are used in many fields, such as agriculture, industry, archaeological and architectural studies, and entertainment purposes. UAVs are preferred in the mapping industry and especially in photogrammetric studies, thanks to their autonomous and semi-autonomous use, the payloads they can carry, and the GNSS-IMU system [10].

Iterative Closest Point (ICP) is an algorithm for measuring similarities between two-point clouds and aligning these point clouds with each other. Usually, the first point cloud is created by scanning a real object,

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while the second point cloud is a virtual point cloud produced by a model [11]. ICP is a widely used algorithm, particularly in robotics, 3D modeling, and object recognition [12,13].

In this research, point data from the historical bridge consisting of a single bridge arch and an additional stone bridge wall with an estimated construction date of 1998 belonging to the State Hydraulic Works (DSI) was produced using TLS and a mobile device application based on the SLAM algorithm. The upper part of the bridge was produced from UAV data with a photogrammetric flight plan. Point data were obtained from UAV images, and point data was produced by TLS and SLAM algorithms separately. The operator combines manual joining and the Iterative Closest Point (ICP) algorithm. The results were compared to perform a spatial accuracy analysis.

2. Method

The technical equipment used in the research, the study area, and the algorithms used are presented in this section. The continuation of this section includes the findings and discussions.

2.1. Terrestrial laser scanner

Faro Focus 3D X330 equipment was used in the study (Figure 1). The TLS provides a 3D image by scanning indoor and outdoor scans quickly and in detail.

Figure 1. FaroFocus 3D X 330

The scanning process is carried out by deflecting the infrared laser beam sent to the center of the TLS rotating mirror to the scanned environment, the receiver of the TLS receives the beam reflected from the surrounding objects, and the scanning process is completed. TLSs differ in themselves as a distance measurement method. The TLS distance measurement methods used in the study work with the phase comparison method. The phase comparison method determines the distance between TLS and the object by measuring the phase differences. TLS amplitude modulation working with the phase comparison method emits one wave, and this modulation includes several wavelengths [5,14]. The distance between TLS and the object is determined by calculating the phase difference between the transmitted and received signals (Figure 2).

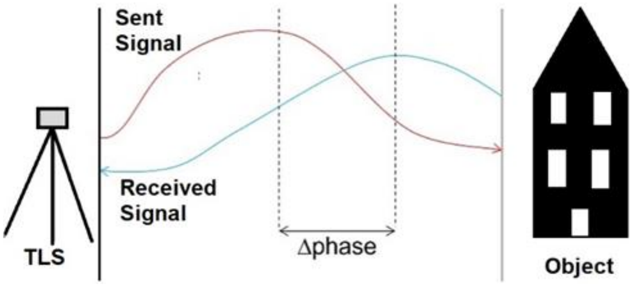

Figure 2. Phase difference distance measuring method

2.2. SLAM based the mobile application

The SLAM is an algorithm that simultaneously analyzes the current location of the autonomous vehicle or mobile system while creating a map of the environment in autonomous vehicles or mobile systems [15]. While mapping and positioning were solved separately in recent years, today, they are solved simultaneously with the SLAM algorithm [16]. Lidar, sonar, IMU, IR, camera, and GNSS support the SLAM algorithm. Systems using the SLAM algorithm work fast, safely, and with fewer errors [17]. The SLAM algorithm is used in autonomous driving electric vehicles, backpack lidar systems, unmanned aerial vehicles, smart home appliances, and smartphones. In this study, it is done by visual slam application with Iphone brand smartphone. Application works in this algorithm:

1. Turn around the object with camera in a specific distance and use GCPs in camera frame,
2. Then specify the object with one tour of around the object and,
3. Create point cloud from that data, taken from object.

In order to use a mobile application based on the SLAM algorithm, the iPhone 11 smartphone was preferred in this research. The smartphone has a camera and GNSS supporting the SLAM algorithm, and the SLAM algorithm was used successfully while obtaining images photogrammetrically (Figure 3) [18].

2.3. Unmanned aerial vehicle

The study used the Rotary wing Parrot Anafi as the UAV (Figure 4). With a total take-off weight of 320 g, Anafi is suitable for 3D modeling works for photogrammetric purposes, thanks to its small size, ease of use, and speed. In addition, since it is classified as a toy by the General Directorate of Civil Aviation (GDCA), it is preferred because it can be flown without legal permission.

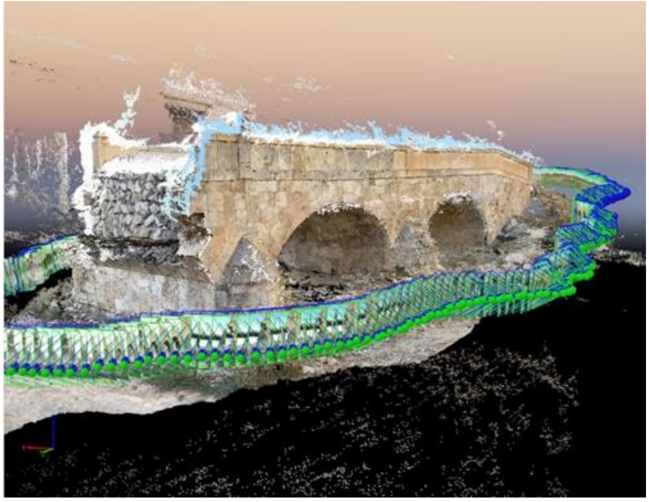

Figure 3. SLAM application

Table 1. Parrot ANAFI Specs

Weight	320 gr
Max. Communication Distance	4 km
Max. Flight Time	25 min.
Wind Resistance	14 m/sec
Max. Vertical Speed	4 m/sec
Max. Horizontal Speed	15 m/sec
Integrated RGB Camera	1'' CMOS 20 MP

Figure 4. Parrot Anafi

The images obtained after the UAV flight performed with photogrammetric-based flight planning are evaluated by software containing newly developed image processing techniques. Such software has complex algorithms using the Structure from Motion (SfM) algorithm [6].

According to photogrammetric acquisition techniques, the SFM algorithm allows obtaining the 3D structure of an object whose side and forward overlapped images were taken in the digital environment [19,20]. Digital surface model, orthophoto and 3D model of cultural heritages can be created with photogrammetric acquisition techniques [21,23].

2.4. The data obtained from object

A total of ten Ground Control Points (GCP) has been positioned, eight are around the historic bridge, and two are on the bridge's road surface. GCPs measured with Continuously Operating Reference Station (CORS) technic. The GCPs were measured at TM 3° projection, 33° slice of ITRF 96 datum (Figure 5).

Figure 5. GCP Measurement

In order to obtain point data on the upper surface of the historic bridge, a UAV flight was carried out. The flight carried out in an area of 400 m^2, took 3 minutes and 37 seconds. The ground sampling distance (GSD) in the flight performed at an altitude of 10 m is 0.39 cm/px (Figure 5). Point data consisting of 12.044.504 points was obtained by balancing the 105 images obtained after the flight in the software. The software performs the adjustment process using the SFM algorithm.

With TLS, the historical bridge, including the side wall above the arc, the arc's outer surface, and the arc's inner surface (in short, all parts except the road part), were scanned. The session plan of the related scan is presented in Figure 7.

The TLS was positioned at six points in the planned session, and scanning was performed. Sessions lasted between 8 and 9 minutes on average. The collected data were adjusted in a software (SCENE), and merged point cloud data was obtained.

The point cloud of all parts of the historical bridge was obtained from the field without coordinates. The obtained data were balanced and transferred to Cloud Compare software in order to convert them to a geodetic coordinate system and combine point clusters.

2.5. ICP algorithm

The ICP algorithm initially applies transformation operations to minimize the differences between the point clouds. This process involves iteratively updating the transformation matrix, which aligns point clouds to each other. The ICP algorithm minimizes the least squares error function between the first- and second-point clouds. This increases the accuracy of the alignment process and improves the final alignment result.

Figure 6. The photogrammetric flight plan of UAV and study area

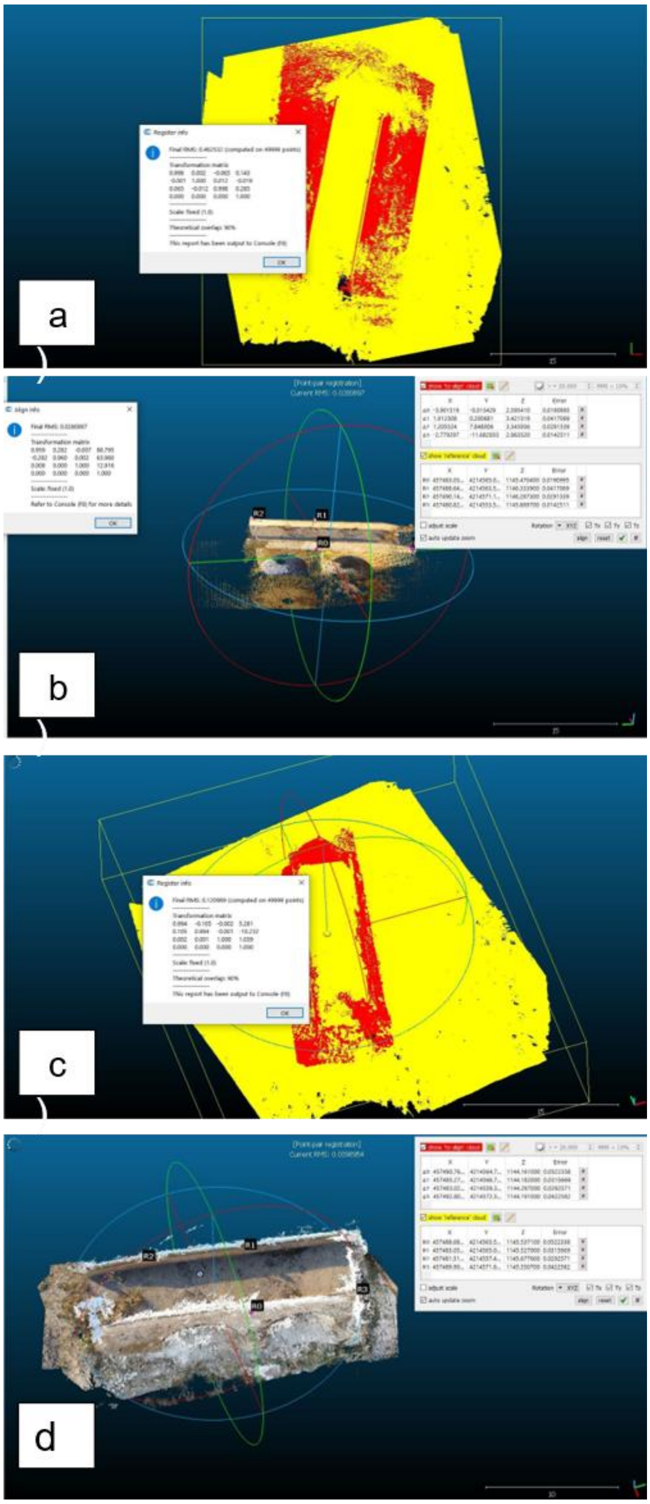

Figure 8. Alignment results (RMSE) of the study (a: UAV-TLS with ICP, b: UAV-TLS manually by operator, c: UAV-SLAM with ICP, d: UAV-SLAM manually by operatör)

3. Results

Point data from UAV images, point cloud obtained by aligning TLS sessions, and point data produced with the SLAM algorithm were combined in Cloud Compare software with two different methods. The first method made by the operator according to their visual suitability is called manual combination, and the combination performed automatically by the ICP algorithm is called the ICP combination. Cloud Compare, the free and open-source software used for aligning point data, offers a relative accuracy for the obtained point clouds. This accuracy is revealed by calculating the root mean square error (RMSE) between the points within the system itself

(Figure 8). The alignment results of two different methods are presented in Table 2.

Table 2. General comparative findings (RMSE)

Data Type	Accuracy (m)	
	Manually	ICP
UAV-TLS	0.028	0.462
UAV-SLAM	0.040	0.121

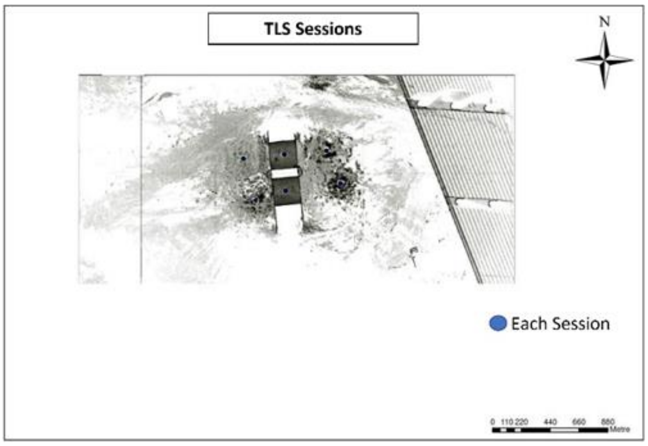

Figure 7. The TLS session plan

Although the visual combination results are satisfactory, the findings obtained regarding positional accuracy show that the manual method provides high accuracy.

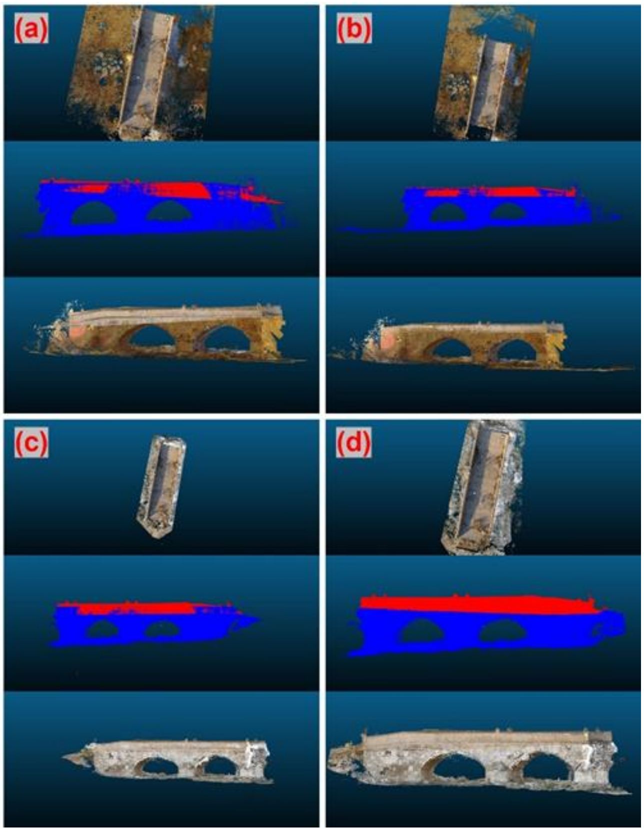

Figure 9. Alignment of point data (a: UAV-TLS with ICP, b: UAV-TLS manually by operator, c: UAV-SLAM with ICP, d: UAV-SLAM manually by operator)

Point data obtained from the ICP algorithm combined with UAV and TLS data is presented in Figure 9a. The combination time of the algorithm is 11 minutes and 27 seconds; the model accuracy is 46 cm. When the operator combined the same data manually, the process took 22 minutes and 43 seconds, and the model accuracy was 3 cm (Figure 9b).

Additionally, point data obtained from the ICP algorithm combined with UAV and SLAM data is presented in Figure 9c. The combination time of the algorithm is 08 minutes and 33 seconds; the model accuracy is 13 cm. When the operator combined the same data manually, the process took 19 minutes and 57 seconds, and the model accuracy was 4 cm (Figure 9d).

4. Discussion

It has been seen that the ICP algorithm, which can combine automatic point clouds, provides users with significant time savings while giving critical negative results in model accuracy. Both types of aligning offer visually positive results. However, the combined time-model coordinate linear relationship reveals the inverse relationship between operator coupling and ICP algorithm aligning.

In the absence of similar working principles of point-generating sources, the accuracy of automatic aligning decreases relatively. For this reason, in aligning point clouds obtained from different data sources, manual alignment by the operator takes longer than the ICP but with higher accuracy.

5. Conclusion

In the research, the 3D model of the historic bridge in the Dokuz District of Konya was produced using a mobile device application based on the UAV, TLS, and the SLAM algorithm. The operator combined point data manually and automatically using the ICP algorithm. Both methods determined that manual aligning by the operator gave more accurate results than the automatic aligning technic with the ICP algorithm.

Author contributions

Hasan Bilgehan Makineci: Conceptualization, Methodology, Data curation, Writing-Original draft preparation, Software, Validation. **Kasım Erdal:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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