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Comparison of techniques used in three-dimensional modelling of small-sized objects with mobile phones

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Abstract

Many cultural assets have not survived from the past to the present without preserving their structural integrity. In order to maintain our connection with the past, many techniques have been developed to protect these cultural artifacts. One of these techniques is based on the photogrammetry technique, which is a technique developed by the discipline of surveying engineering, in which the physical dimensions of the object are measured geodetically without contact with the objects and their three-dimensional models are produced in a computer environment by taking their photographs considering photographic rules. Thanks to this technique, all the geometric and structural features of the structure, metric information, and details of the object's integrity such as material type can be revealed. Modelling techniques and scanning methods have also developed with developing technology. In recent years, with the development of three-dimensional scanning technologies, it has become quite easy to transfer physical objects to digital media. Thanks to these methods, an existing object can be quickly transferred to digital media and then changes can be made to this digital model or preparations can be made for production. Three-dimensional modelling accelerates design processes, reduces costs and increases production quality. In addition, it can be widely used in engineering, industry, geology, archaeology, virtual reality and augmented reality applications. In this study, a three-dimensional modelling of a small object was made using the lidar scanning method, which is one of the advanced scanning methods of today, and photographs taken with the same mobile phone camera using an iPhone 14 Pro model mobile phone lidar sensor. Modelling was done using the 3D Scanner App software and the scanning techniques allowed by the software were compared. The creation times of the model obtained with each scanning technique, the number of photographs used, the model integrity and sharpness, the reference measurements obtained from the object and the measurements obtained from the model were compared and statistical values were obtained from these data. In the light of this data, it was discussed which scanning technique and model gave better results.

1. Introduction

Cultural heritage is very important assets that shed light on past civilizations and their lifestyles, cultural structures, traditions, belief styles, daily life routines and disasters they have experienced. In this respect, the preservation, maintenance and repair of this heritage and its transfer to the next generations is of great importance. At the same time, today, the economic, cultural and promotional value that these assets add to the country in the international arena is quite high [1,2]. In this respect, the better the cultural heritage can be preserved, the higher the value it adds. Cultural heritage has a representation about the place it belongs to in terms of the values it reflects. Therefore, in order to protect and promote these assets, different techniques are constantly being developed to document, visualise and present their features better [3].

Recently, various methods and approaches for three-dimensional documentation and modelling of small-scale artefacts have been developed and many studies have been conducted in this field. The main characteristics of the digitization of a small object may vary depending on the size of the object. These variations determine how to adapt the techniques and technologies used according to the physical characteristics and scale of the object [3,4].

Photogrammetry technique is a method frequently used in the digital documentation of cultural heritage. In this method, studies such as three-dimensional model, visualization, location data, spatial analysis of cultural heritage are carried out by obtaining images of the object in accordance with measurement and photographic rules without physical contact with the objects. This technique has been used in the documentation of cultural heritage for a long time and with the recent technological developments, it has become more ergonomic in terms of cost, more technically usable and more sensitive in terms of sensitivity.

LIDAR (Light Detection and Ranging) is a measurement technique that generates very large point cloud data containing 3D position information of the scanned object or region by sending thousands or millions of laser signals per unit time [5-7]. LIDAR technology was first used in aviation applications in the 1960s [8-10]. In the 1970s, it was used as a remote sensing sensor and was used in various applications in places such as seas, forests and atmosphere in mapping the earth's surface [11-14]. Nowadays, thanks to the huge developments in technology, the LIDAR technique has developed to the same extent and three-dimensional point data are obtained by using different techniques as aerial, ground and mobile LIDAR according to the object or area to be studied, and these data are used in many disciplines such as mapping, spatial analysis, 3D object modelling, 3D urban modelling thanks to its possibilities such as mapping, forestry, maritime, industry, engineering [15-18]. LIDAR technology, together with the developing technology, requires expertise to be used in application areas, requires advanced software and hardware to obtain output products, and is also costly devices, which reduces the accessibility of LIDAR and increases the costs of uncomplicated scanning and modelling considerably [19-21]. With the developments in the field of technology in recent years, with the integration of the LIDAR sensor into smartphones and tablets, studies that require less precision and expertise such as spatial mapping [22-24]., 3D mapping, 3D object modelling, virtual reality applications and reverse engineering applications have started to be carried out easily and at low cost [25-28]. 3D modeling is done with both photogrammetric methods and lidar. Nowadays, lidar technology is at the forefront [29-31]. In this study, the usability of the LIDAR sensor scanner and camera in the Apple 14 pro model via the '3D Scanner App' application downloaded from the Apple application store and the applicability of the scanning techniques in the application were examined. The geometric dimensions of the scanned objects were compared with their real dimensions and their accuracy was investigated. In this way, it was tried to reveal the usability of the integrated LIDAR sensor and other modelling techniques in 3D modelling.

2. Method

In the study, the iPhone 14 pro model of the Apple smartphone series was used to realize the application. iPhone 14 Pro is a model introduced by Apple in 2022 and offers very powerful features in terms of camera and LIDAR sensor. The features of this camera and sensor (Figure 1) are listed below. The mobile application where the study was carried out is the '3d Scanner App' application downloaded from the Apple store.

2.1. Camera features

Main Camera (Wide Lens):
Resolution: 48 MP, f/1.78 aperture
Sensor: Large format, 24 mm equivalent focal length

Ultra Wide Camera:
Resolution: 12 MP, f/2.2 aperture
Sensor: 13 mm equivalent focal length

Telephoto Camera:
Resolution: 12 MP, f/2.8 aperture
Sensor: 77 mm equivalent focal length
Features: 3x optical zoom, optical image stabilizer (OIS), 4K Dolby Vision HDR video recording [17].

Figure 1. Iphone 14 pro camera and sensor system [13]

2.2. LIDAR sensors

LIDAR Sensor: iPhone 14 Pro includes a LIDAR (Light Detection and Ranging) sensor in the rear camera system. This sensor performs highly accurate 3D mapping using a laser beam to measure the depth of the environment.

Features:

Auto Focus: Provides faster and more accurate autofocus, especially in low light conditions.

Portrait Mode: Enhances depth perception in portrait shots, providing more natural and sharp background blur (bokeh).

AR Apps: Supports better operation of augmented reality (AR) applications, better detecting and positioning objects in the environment [17].

2.3. 3D Scanner App

3D Scanner App software is a simple tool for creating 3D models of objects and spaces in minutes or even seconds. In this way, it has been developed with the aim of being an application that can be used instead of expensive and cumbersome to carry and use measuring devices for three-dimensional object modelling and spatial analysis needed in virtual reality, reverse engineering, hobby purposes and various professional disciplines that do not require high precision (Figure 2).

Scan mode	LIDAR, LIDAR Advance, Point Cloud, Photos, TrueDepth
Scan settings	Resolution, max depth
Processing options	HD, Fast, Custom
Processing steps	Smoothing, simplifying, texturing
Export as	Point cloud, mesh
Export formats	PCD, PLY, LAS, e57, PTS, XYZ, OBJ, KMZ, FBX etc.

Figure 2. 3D Scanner App features

When looking at the application interface, as shown in Figure 3, there are scanning modes such as LIDAR, LIDAR advanced, Point Cloud and Photos. The aim of this study is to determine which scanning mode gives better results in terms of both visual and sensitivity. For this purpose, the cist object given in Figure 4 was scanned using each scan mode.

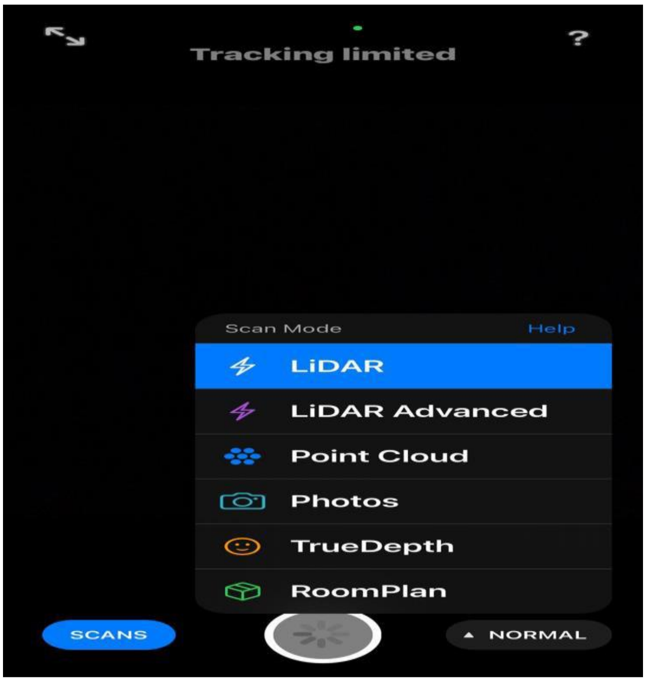


Figure 3. 3D Scanner App software scanning modes


Figure 4. The cist object subject to scanning

2.4. Study

In the study, firstly, scanning was performed in the normal mode of LIDAR, which is the first of the scanning modes shown in Figure 3. In this scanning mode, there is no adjustment correction that allows adjustment for scanning the object. The object was fixed on the ground and scanned around the object. After the scanning was finished, the 3D model was created as shown in Figure 5 after the processing of procces and texture. The object was kept stationary and the scanning process was carried out with slow movements around it. During scanning, a distance of approximately 30-50 cm was kept between the object and the camera. After the scanning was finished, it was observed that the processes of processing and texture took approximately 46 seconds and 35 photographs were scanned during these processes.


Figure 5. Model image created with LIDAR normal

In the picture shown in Figure 6, the type of the object to be scanned is determined by using the 'MASKING' button in frame 1, the approximate size of the object is determined with the 'RESULATION' button in frame 2, the quality setting with 'CONFIDENCE' in frame 3 and the scanning distance of the object is determined with the 'RANGE' button in frame 4. Scanning distance is very important for the object to be scanned. Considering the features of the mobile application, it is stated that the best scanning distance is at an arm's length from the object, i.e. approximately between 0.5-1 m (Figure 7).

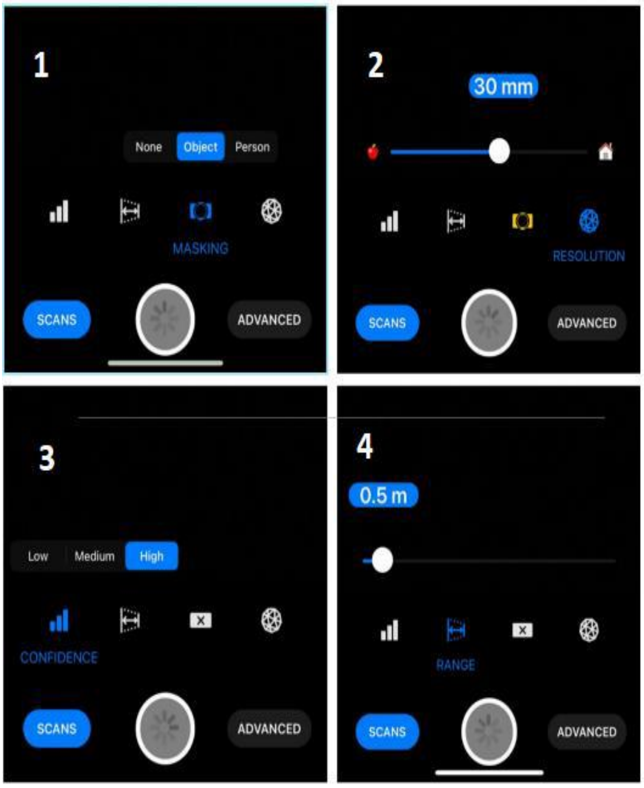


Figure 6. LIDAR advanced scan settings

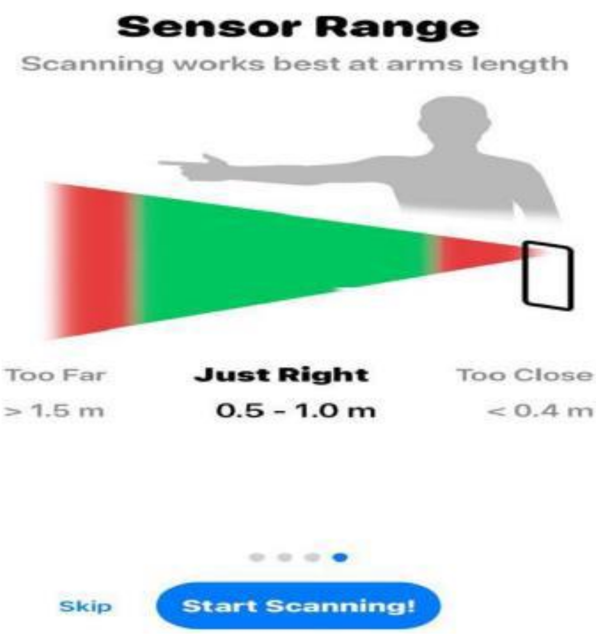


Figure 7. LIDAR scan quality range

Considering the scanning distance shown in Figure 7, the distance between the object and the object was approximately 30-50 cm and scanning was started by adjusting the scan settings shown in Figure 6. The selection of the object option as masking during scanning and the selection of the scanning distance according to the size of the object shortened the data size, procces and texture processing times, since unwanted objects were not scanned during scanning. These operations were carried out in a short time of approximately 10 seconds. During this scanning, 137 images were taken. The 3D model obtained at the end of the scanning process is given in Figure 8.

Figure 8. 3D model image obtained with LIDAR advanced scanning mode

As a result of the scanning of the object using the point cloud mode, the point cloud was created as shown in Figure 9. The scanning distance was kept in the range of 30-50 cm as in previous scans. During this time, 113 images were taken. Since the 'RANGE' module, which is the object scanning distance, was not available in this scanning option, the scanning of areas outside the object could not be prevented. Other objects around the object were also scanned. At the end of the scanning, a sparse point cloud was obtained and a dense point cloud was obtained as a result of the procces process. However, since the mobile application does not provide the opportunity to create the model after the scanning process of the object such as texture and mesh creation processes, the study was limited to the point cloud obtained.

Figure 9. Point cloud image of the object

As the last stage of the application, the 3D model of the object was obtained by using the 'Photos' module of the 3D Scanner App thanks to the photogrammetry technique. During the application, photographic rules were taken into consideration in order to obtain the model in a healthy way. Care was taken to ensure that the obtained photographs could be taken in an overlapping manner by covering the entire object, and a precise value for the overlap ratio was not calculated, but a coverage of approximately 85% was taken. In order to take the photographs in a certain alignment position, the camera was fixed and the object was placed on a platform that can rotate around itself and a total of 51 photographs were taken in series using the auto-shooting feature of the application. The distance between the object and the camera was kept at approximately 30 cm. After the shooting process was completed, upload and procces continued. These processes took approximately 3-4 minutes and the 3D model shown in Figure 10 was obtained.

Figure 10. Visual examples of the 3D model obtained using the 'Photos' module

Both visual and metric accuracy of the models obtained as a result of the study were analysed. In particular, in order to analyse the metric accuracy, the actual lengths of the scanned object, the cist, as shown in Figure 11, were measured and compared with the lengths measured on the model. The sparse point cloud obtained through the point cloud scanning performed on the object with the '3D Scanner App' mobile application was converted into a dense point cloud as a result of the procces process, but the point set obtained could not be converted into a 3D model due to the lack of options such as texture and mesh creation in this module of the software. Therefore, since it was not suitable for measuring on the point set, no measurement could be performed. Measurements could be made on the model by using the other scanning options of the mobile application.

The reference lengths measured on the object and the segment lengths measured on the obtained 3D model are shown in Table 1. The mean, squared mean error (mse) and standard deviation (sd) of the obtained differences were calculated and the accuracy sensitivities of the obtained 3D models were revealed and shown in Table 2.

Figure 11. Measured separations of the cist

Table 1. Reference lengths of the object measured with a ruler and lengths measured on the model

Measured Separation Length	Reference Dimensions (cm)	LIDAR (cm)	LIDAR ADVANCE (cm)	PHOTOS (cm)	POINT CLOUD
a	15.20	14.90	14.17	15.31	-
b	10.00	9.76	8.49	10.20	-
c	5.20	5.03	4.12	5.64	-
d	12.90	12.33	11.20	13.00	-
e	7.10	7.08	6.76	7.20	-

Table 2. Differences and statistical data of the reference lengths measured on the object compared to the lengths measured on the model

Measured Separation Length	LIDAR (cm)	LIDAR ADVANCE (cm)	PHOTOS (cm)
a	0.30	1.03	-0.11
b	0.24	1.51	-0.20
c	0.17	1.08	-0.44
d	0.57	1.70	-0.10
e	0.02	0.34	-0.10
Centre	0.090	0.235	0.065
Mse	0.041	0.277	0.021
Sd	0.202	0.526	0.146

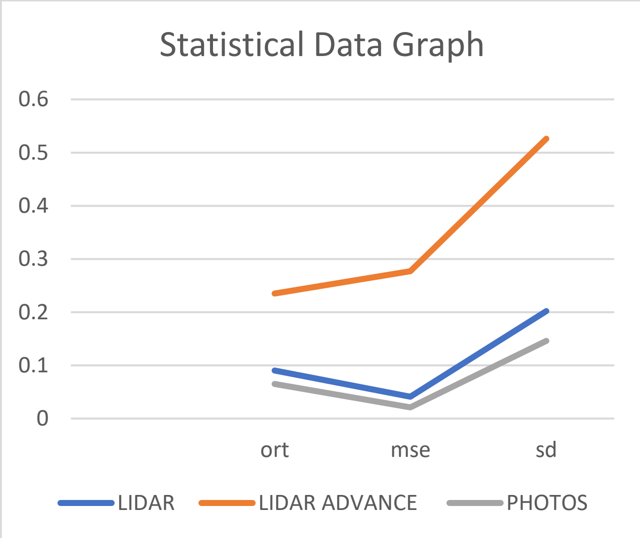
3. Results and Discussion

In this study, it is aimed to test the modelling capabilities of the '3d Scanner App' mobile application of the LIDAR sensor and camera integrated into smart devices, which is one of the 3D modelling techniques needed for small objects in applications such as archaeology, virtual reality, reverse engineering applications, and relay, on a cist object and to reveal both visual and accuracy. While creating the model, it was seen that the glare caused by the excessive light falling on the object and the darkness caused by the low light environment negatively affected the quality of the model, so the object was positioned in the middle of the room and care was taken to ensure that the light came homogeneously to all sides of the object and care was taken to work in the best light.

The 3D models obtained using four different scanning techniques were visually compared and the scanning technique 'PHOTOS' was the closest to the real object in terms of shape and size. The difference between the actual lengths and the lengths measured on the model was minimal and within the acceptable error limits, as shown in Table 2 for the mean error, squared mean error and standard deviation values. The largest difference in this scanning technique was 0,44 cm in the measurement of the 'c', i.e. the height separation of the object. In the scanning technique, 51 images were taken and it was seen that the image dressing time, i.e. texture and mesh creation time, was the longest technique with a range of 3-4 minutes. In addition, it was the most realistic model obtained in terms of model integrity and sharpness of the separations.

As can be seen in the statistical data graph (Table 3), it is determined that the scanning technique with the lowest error amount after the 'PHOTOS' technique is the 'LIDAR normal' technique. Although the mean error, squared mean error and standard deviation data were good, the 3D model of the object could not be integrated and there were shifts in the model integrity. Since this scanning technique does not have settings such as scanning interval and selection of the object to be scanned, it was observed that other unwanted objects around the object were scanned while scanning the object. In the creation of the model, 35 images were used and it was observed that the texture&mesh creation time was 46 seconds. The 'LIDAR advance' technique stands out for this mobile application as a technique that allows adjustments such as proximity distance, scanning distance, and specification of the object to be scanned. These advantages help to reduce both data volume and unwanted noise level by preventing the scanning of unwanted objects around the object. These advantageous adjustments of the technique were made repeatedly and the object was repeatedly scanned. Nevertheless, as can be seen in the visual examples of the model shown in Figure 8, shifts occurred on the model and the integrity of the 3D model could not be ensured. As seen in Table 2 and 3, it was determined that the scanning technique had the largest differences in terms of length differences and statistical data. For the model obtained in the scanning technique, 137 images were taken and the texture & mesh creation process took 46 seconds. With the 'point cloud' technique, 137 images were taken and a sparse point cloud was created by the application over these images as shown in Figure 9. As in other photogrammetric software, dense point cloud was obtained from sparse point cloud as a result of the procces process. However, since the software does not have any module for texture and mesh operations, no operation could be performed. Therefore, no 3D model of the object could be created and no measurements could be taken. Therefore, there is no data obtained from this technique in Table 2 and 3. Since the number of points obtained in this scanning technique is not the subject of any comparison in the study, it is not necessary to mention the number of points.

Table 3. Graph including sensitivity analysis according to the statistical data obtained



4. Conclusion

The technology that has developed over the years has brought many benefits such as digital recording of cultural heritage, spatial analysis, digitalization of archaeological artifacts and excavation area with all the details, reverse engineering applications, cartography activities, especially in many engineering disciplines, such as reducing the cost of 3D modelling, ease of application and saving time. In addition to the advantages of this technology, there are also disadvantages such as the cost of the hardware, the need for expertise, the cost of the software and the inability to easily transport the devices to every point.

With the development of smart phones day by day and the integration of advanced camera systems, their success in obtaining low-cost, precise and extremely high quality image data has paved the way for 3D modelling technology by equipping this technology with software that can obtain 3D models and has brought it to a point where it is accessible to all users.

The fact that this technique, which is used in the modelling of three-dimensional objects, has a very wide user network through smartphones, the software used in modelling does not require expertise, and the ease of obtaining free of charge from the application stores of smartphones, as well as the ability to produce 3D models quickly due to the very short time of obtaining and processing data, shows that this technique will become more widespread in the near future. The comparison of the findings obtained in the study and the screenshots of the obtained models by taking into account features such as data acquisition time, precision, visual quality, final product integrity and sharpness will contribute to the literature on software and techniques that can be used in 3D modelling of small objects with smartphones.

Author contributions

Fatih Pulat: Conceptualization, Methodology, Software, Data curation, Writing-Original draft preparation, Software, Validation. **Murat Yakar:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

Notes

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