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Cultural Heritage conservation Using Portable Laser Devices Embedded in Mobile Phones

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Abstract— There is a need for more documentation and quantitative data on architectural and cultural objects, especially those that are vulnerable to damage or loss. 3D data acquisition technologies, such as the Close-Range Photogrammetric (CRP) approach, are frequently associated with high costs. Alternatively, it may necessitate a significant investment of both time and effort, prompting users to explore cost-effective solutions that allow them to achieve their desired levels of precision. Apple has incorporated a LiDAR sensor into its products, creating a three-dimensional representation of objects or locations. This study aims to assess the precision and accuracy of this sensor in generating three-dimensional depictions of cultural artefacts. This research investigates the potential of iPhone Lidar (IPL) to support cultural heritage preservation, looks at various roadblocks and challenges that can arise, and assesses the technology's efficacy in particular contexts. To evaluate the accuracy of each technique, a case study survey was conducted using close-range photogrammetry (CRP), where the camera of the iPhone 13 Pro Max was used, and a laser scanning survey was also conducted using the iPhone's built-in Idar sensor. For comparison, coordinates were imposed Local artificial targets were placed near the model using a Leica TS 09 Plus total station and were considered as a reference for comparison. The results indicated that the root mean square error (RMSE) for IPL was 8mm, whereas for TLS it was 3mm. The lidar sensor has rapid scanning capabilities at a relatively cheap expense while maintaining an acceptable level of precision. However, it should not be regarded as a replacement for TLS, as the latter is an indispensable instrument for collecting data over wider distances. The causes for this are the sensor's precision, its ability to cover vertical space, and its restricted range, which is capped at a maximum of 5 meters.

Keywords— IPhone lidar (IPL), Laser Scanners, Close Range Photogrammetric, Total Station, RMSE ,3D

Introduction

Documenting cultural heritage is one of the important applications in which photogrammetry is used. Image-based 3D modeling is expected to benefit from this technology development [5]. The goal is to enhance the balance between cost and effectiveness of the results, taking into account aspects such as metric and geometric accuracy, level of complexity, and overall excellence of the data obtained. Therefore, it is imperative to design additional ecologically sustainable and highly effective approaches to complete the documentation process that addresses the requirements of both programmers and consumers. In recent years Systems with increased processing capabilities have utilized the shrinking size of electro-mechanical parts and sensors. Apple unveiled two cutting-edge personal gadgets in 2020, the iPad Pro and the iPhone 12 Pro, with state-of-the-art LiDAR sensors. This introduction represented a notable breakthrough in the field of personal technology. The integration of LiDAR scanning technology into a portable device designed for civilian use has generated considerable enthusiasm among both consumers and skilled operators. Presently, there is a restricted quantity of technical articles accessible that delve into the use of these sensors. The validity of these devices for rapid surveying applications is still being established. Hence, this research aims to evaluate the efficacy of this sensor in documenting cultural heritage. This type of employment utilizes the latest advancements and cutting-edge technology.

The primary advantages include exceptional data precision and the absence of any requirement for direct physical contact with the scanned object. This study article aims to assess the capability and effectiveness of the iPhone 13 Pro Max in capturing and preserving cultural heritage, The integration of LiDAR technology with a mobile device designed for consumer use has generated considerable enthusiasm among all consumer and professional users. At now, there is a scarcity of technical literature regarding the utilization of these devices for expedited surveying purposes. The verification of the achievable accuracy with these devices is still pending. the accuracy of the sensor is evaluated by comparing the results of a conventional survey conducted with a total station and the point cloud generated using CRP

1. A review of literature

The data acquired from the Apple iPhone were compared to a reference dataset obtained by TLS or close-range photogrammetry (CRP) in each instance. The authors highlighted that considerable interference in the acquired point cloud is a major obstacle in utilizing this technique for cultural documentation. However, employing customized methodologies, the utilization of Apple LiDAR in this field could yield promising outcomes.

The study done by [12] focused on evaluating the capabilities of the latest Apple products for industrial 3D scanning. The researchers specifically investigated the potential of LiDAR technology and its frontal TrueDepth camera. The researchers performed a comparative investigation of the two sensors by assessing their performance on small objects, specifically LEGO bricks, and comparing the collected data to that of a corporate 3D scanning system. More precisely, they focused on the impact of the coloring of the selected bricks on the process of scanning and the overall scan quality. The authors' inference is that, considering the present degree of advancement, these technologies might not enough for the majority of industrial applications. Nevertheless, they might be appropriate for specific applications with less stringent precision demands.The study conducted by [2] offers an initial assessment of the application of Apple LiDAR technology for the purpose of documenting cultural heritage. The iPad Pro has been used to evaluate two software applications that enable the acquisition of point clouds. The testing was carried out in three specific scenarios: (i) capturing tiny to medium-sized objects, (ii) capturing the external façade of buildings, and (iii) mapping the interior spaces.

The authors [7] have explained some aspects related to the application of Apple LiDAR in forest inventory. Three separate applications were evaluated, each using a customized approach to data collection. The obtained results were subsequently compared with scale-based approaches and traditional measurement methods employed for assessing tree diameter. The conclusion reached by the authors is the fact that the iPad LiDAR provides expedited and versatile techniques when compared to conventional measuring protocols. Nevertheless, it is crucial to acknowledge that attaining exceptional levels of precision and spatial detail remains unattained in this specific situation. [8] conducted an evaluation of the iPhone 12 Pro's usage in performing 3D surveys of stones and cliffs for geological purposes, utilizing several programs. This assessment emphasizes the considerable potential and efficiency of the small technologies integrated into a smartphone. Prior study on the initial assessment of Apple LiDAR capabilities has consistently recognized the incorporation of this type of imaging into consumer-grade personal devices as a groundbreaking advance. In addition, the authors of this study, [3], who also performed an initial evaluation of Apple devices outfitted with LiDAR sensors, foresee significant progress in the coming years. [15] conducted an evaluation of the iPhone 12 Pro's precision in utilizing the global navigation satellite system (GNSS), effectiveness of its inertial measurement unit (IMU) and magnetometer, proficiency in shooting photographs and videos, and the application of its LiDAR sensor for geological studies. The GNSS receiver of the iPhone 12 Pro exhibits rapid and precise data collection within a few meters, rendering it a formidable choice in comparison to other mobile devices that achieve comparable accuracies but require more time to do so.

A recent study conducted in Iraq in 2023 utilized the IPL to capture the exteriors of historical sites and evaluate the precision of data in a unique local research application. The precision of IPL was evaluated by a range of engineering quality examinations. In addition, the influence of the range on the quality of the data was investigated, and the data was compared to measurements taken as a reference. The ancient structures' exteriors were subsequently scanned using different scan patterns and setups. The acquired data was subsequently merged utilizing (TLST) through a 3D scoring method that depends on inherent targets. The accuracy tests performed on the iPhone sensor exhibited millimeter-level precision while scanning within a 5-meter range. The level of precision was determined to be comparable to that of a TLST sensor functioning within the identical range. The IPL sensor produced very detailed scans at close distances of 0.25 μm when set to high quality settings. Although this sensor has significantly reduced the time needed for data collection, it should not be regarded as a replacement for TLST. The use of TLST continues to be an essential tool for gathering data on a larger scope. The sensor's inherent constraints, including its restricted range (up to 5 meters), vertical scope, and resolution, account for this. phenomenon. Despite these limitations, it is expected that there will be improvements and progress in the technical specifications of the sensors in the future[14]

1.1 *Summary*

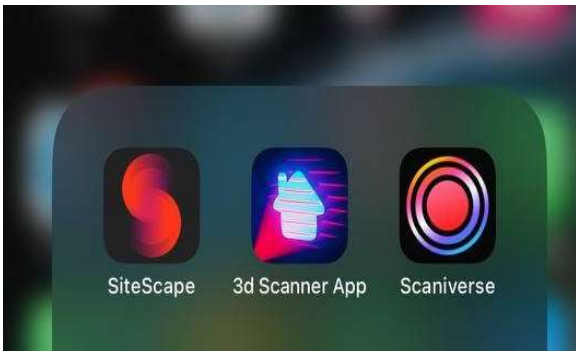
Table (1) showes the summary of literature review.

Table 1: the summary of literature review.

AUTHOR-YEAR	DEVICE	APPLICATION	SUMMARY
(Vogt, Rips and Emmelmann, 2021)	IPL	conducted tests on the potential of the most recent Apple products for industrial 3D scanning	these devices may not be enough for most industrial applications. However, they may be suitable for particular applications that have lower precision requirements.
(Murtiyoso *et al.*, 2021)	IPL, TLS	first evaluation on the use of Apple LiDAR for the goal of documenting heritage	The authors emphasized that a significant challenge associated with using this method for heritage documentation is the substantial amount of noise in the captured point cloud. Nevertheless, by using tailored techniques, the use of Apple LiDAR in this domain might provide encouraging results.
(Gollob *et al.*, 2021)	IPL	presented some points about the use of Apple LiDAR for the purpose of forest inventory	the iPad LiDAR offers quicker and more adaptable methods in comparison to traditional measuring procedures. However, it is important to note that achieving high levels of accuracy and spatial resolution has not yet been accomplished in this particular scenario.
(Luetzenburg , Kroon and Bjørk, 2021)	IPL	use of the iPhone 12 Pro by using several applications for conducting 3D surveys of rocks and cliffs for geological reasons	The previous research conducted on the preliminary evaluation of Apple LiDAR capabilities has unanimously acknowledged that the integration of this technology into consumer-grade personal devices is a revolutionary innovation.
(Tavani *et al.*, 2022)	IPL	assessed the iPhone 12 Pro's accuracy in using the global navigation satellite system (GNSS)	The study highlighted the benefits of user-friendly iOS applications for accurate surveying and the device's portability in the field. However, some apps, like Pix4Dcatch, had limitations in terms of online data processing, as it required uploading data to the cloud. Additionally, a 'doming effect' was observed in the geometric reconstruction of the scene.
(Fadhil and Abed, 2023)	IPL, TLS	record the exteriors of historical structures and assess the accuracy of data in a novel local research application.	IPL sensor has really decreased the time required for data collection; it should not be seen as a substitute for TLS. TLS remains a crucial instrument for collecting data on a wider scale. The sensor's intrinsic limitations, such as its limited range (maximum of 5 meters), vertical coverage, and resolution, are the reasons behind this. Notwithstanding these constraints, it is anticipated that there will be enhancements and advancements in the specifications of the sensor in the future

2. Exploration iphone lidar application

An assortment of software, specifically designed for laser scanning, was examined in the Apple Store. Among the multiple of applications accessible from the Apple Store (fig.1), Scaniverse, 3DScanner app, and Sitescape are the most popular. However, each of these applications has its own set of pros and limitations. An essential factor to consider is the performance and behaviour of applications that produce point clouds on the iPhone. The duration it takes for the device to create the model, along with the quality, format, and size of the results, are all significant factors that impact time and effort savings. Consequently, three apps underwent testing on the Water Fontain (WF) case study, which is a small fountain located in the University of Baghdad's College of Engineering Deanship's backyard.



(a)

(b)

Figure 1: (a) applications in Apple store, (b) Water Fontain (WF) case study

3. Case study

The slab included a distinct relief depicting a youthful with a radiant halo encircling his head and a crescent moon. The sculpture of the deity Barmarin, known as the son of Barmarin, is depicted wearing a dress with overalls as shown in fig 2. It has a naked leg and it is wearing sandals. His upper garment is wrapped around his waist, and he holds a sword in his left hand while holding a stick with an eagle-shaped top in his right hand. The sculpture is made of white marble that has turned gray over time. It is located inside the Iwan of the great temple in the city of Hatra. The sculpture dates back to the Hellenistic period, specifically between 312 and 139 BC [1] .

Figure 2: SGB case study.

4. Methodology

To assess the accuracy of the point clouds generated by the Apple iPhone 13 Pro Max and CRP, a precise coordinate system was established by conventional surveying methods. It will serve as a benchmark for evaluating the precision of IPL and CRP.

4.1 *Traditional survey*

In the conventional survey conducted with the Leica TS 09 Plus total station gadget, a synthetic target was positioned in close proximity to the model. Coordinates for the targets were imposed and used as a reference to measure the accuracy of the IPL sensor using total station [6]. Notably, the museum administration has implemented a prohibition on the installation or handling of ancient relics in order to conserve them. This has posed challenges in mounting the targets directly onto the objects. A Leica 09 plus 1 second Total Station gadget was utilized to establish coordinates and oversee these stationary targets employing the non-prism mode, as depicted in figure 3.

Figure 3: SGB case study with artificial targets.

4.2 *Iphone lidar (IPL) SURVEY*

For the laser scanning with (IPL), the Sitescape tool was utilized for this specific objective. It is widely regarded as the most proficient in generating point clouds [10]. SiteScape (Version 1.7.13) allows for customization of the "point density" and "point size" by selecting from options such as "low", "medium", or "high". The term "point density" refers to the quantity of points captured, with "medium" and "high" quality indicating two and four times the number of points gathered in the "low" quality mode, respectively. Furthermore, the "point size" exclusively impacts the dimensions of points that are observable in real-time, rather than altering the recorded data set itself [9]. According to [4], to get the most accurate and precise cloud production for medium and small sizes with fine features, it was recommended to increase the density and decrease the point size. By utilizing the sitescape application, a single scan was conducted on the SGB using an iPhone 13 Pro Max. This scan, which lasted around 1 minute, effectively covered the whole SGB area. A total of 1,605,848 points were scanned. The point cloud with color information was exported in PLY format. The outcome of the scanning operation is depicted in Figure 4.

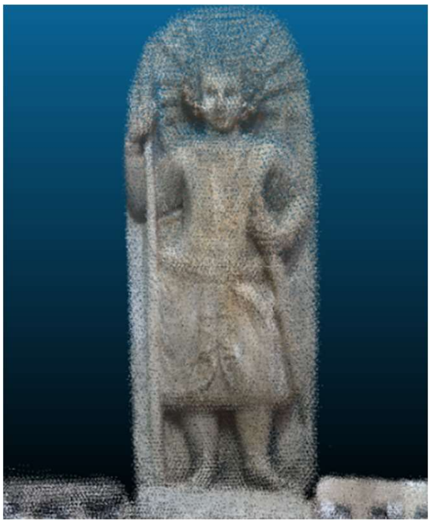


Figure 4: IPL result.

4.3 *Close-Range Photogrammetry (CRP) survey*

As for the CRP technique, the iPhone 13 Pro Max camera was used. It accounted for the camera settings (ISO, shutter speed, aperture, data format, etc.). The documentation process requires taking many photos in different locations and levels, provided that they overlap with each other, The distance between the phone and the model was 1.5m as shown in the Figure 5. The number of photos taken initially is (114) to cover the object completely. the result is clear in Figure 6.

Figure 5: Image acquisition scenario, as it is required by SfM photogrammetry with large overlaps and different locations and angles [13].

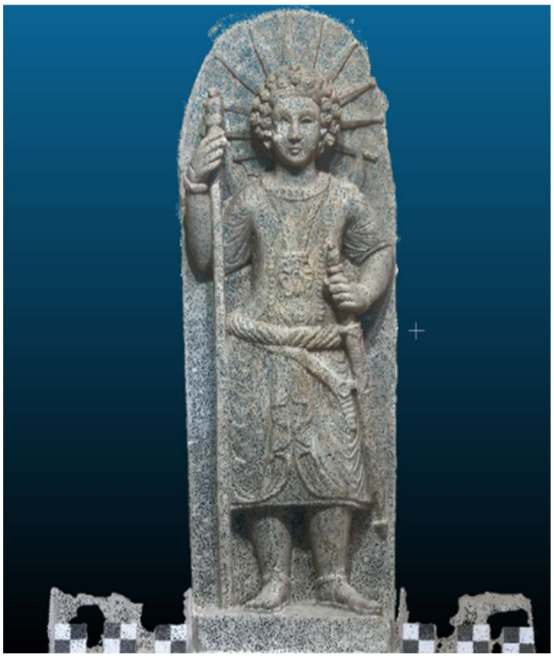


Figure 6: CRP result.

5. Analysis and results

5.1 *Applications performance analysis*

Table 2 is summarizing the final analysis results delivered from individual apps.

Table 2: Application analysis.

	Sitescape	Scaniverse	3d scanner app
Cost	Free for sitescape, 49.99$ for pro version	Free	Free
Output	3D point cloud	3D mesh	3D mesh
Ease of use	High	Medium	Medium
Speed of performance	Faster in 3D modelling	Slow in 3D modeling	Slow in 3D modeling
File format	E57, ply	FBX, OBJ, GLB, USDZ, STL, PLY, LAS	OBJ, GLTF, GLB, STL, PCD, PLY, PTS, XYZ, LAS, E57, FBX

Following the scanning process, the 3D Scanner program and Scaniverse provide a three-dimensional mesh as their output, aligning with the discoveries of [2] and [11]. They belong to the post-processing software category. This suggests that the process of constructing a 3D model necessitates a certain amount of time after the capturing technique. This procedure adversely affects the functioning of the processor, leading to an increase in the device's temperature and a substantial decrease in the battery's charge level. Naturally, the device's performance is influenced by the size of the file. If the processing time of the 3D Scanner program exceeds around five minutes due to the file size, it will halt processing. Consequently, the file size increases as the area to be scanned becomes larger. The Sitescape app eliminates the requirement for post-processing data after the scan phase by promptly delivering the processing results as a point cloud. The format of the finished file is a crucial and noteworthy consideration for the user. The E57 format is often preferred for exporting data for post-processing. The format may be easily accessed through the 3D Scanner, Sitescape, and Scaniverse programs, which proved highly beneficial for our specific needs. During this inquiry. As previously said, the Sitescape app outperforms the other applications analyzed in this study in terms of generating the quickest outcomes.

5.2 *SGB analysis*

Both clouds were imported into the Cloud Compare software in E57 format for comparison and analysis. The findings exhibited variability in the quantity of points. CRP generated a total of 843,588 points. Although the IPL has generated a total of 1,605,848 points, surpassing the total amount of points earned by CRP, this numerical dominance does not necessarily indicate that the IPL is of superior quality compared to CRP. Conventional survey data were employed as a benchmark to assess the precision of the point cloud for both methodologies. The IPL had a root mean square error (RMSE) of 0.011044, whereas the RMSE for CRP was 0.66mm. Based on these data, it may be inferred that CRP exhibits higher spatial accuracy compared to IPL. In order to ascertain the spatial correctness of both vertical and horizontal data, specific targets (2,3,5,6,8,9) were selected to assess any discrepancies in the coordinates (X, Y, Z) by comparing them to survey data obtained through the use of a Total Station. The coordinates were manually recorded and inputted into the Excel software to compute the error (ΔX, ΔY, ΔZ).) as shown in Table A in the Appendix. The subsequent graphic displays the Root Mean Square Error (RMSE) values for both cloud datasets.

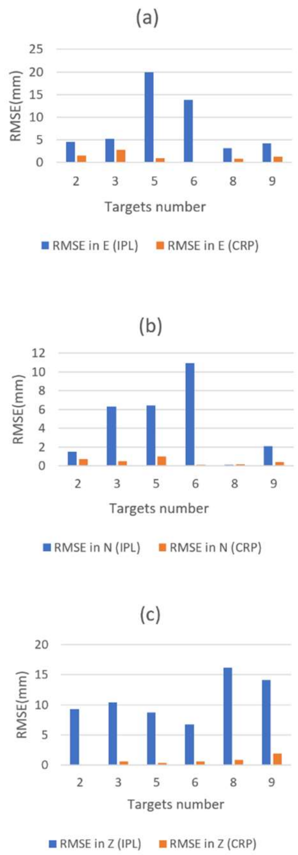


Figure 7: The simulation of the errors of the selected targets where each chart represents: a) The errors in X, b) The errors in Y, c) The errors in Z.

A roughness test was performed using the software Cloud Compare to determine which application provides data with less noise. This was achieved by evaluating the precision level of every set of data using the roughness statistical analysis test. The CRP exhibited a standard deviation of ±0.2mm, but the IPL exhibited a standard deviation of ±0.4mm. These results strongly suggest that the precision of CRP, in terms of its roughness, provides valuable insights into the modeling features obtained from the point cloud models. Conversely, the CRP data produces a highly detailed point cloud with minimal noise and maximum smoothness and softness, thanks to its low level of roughness. Refer to the diagram.

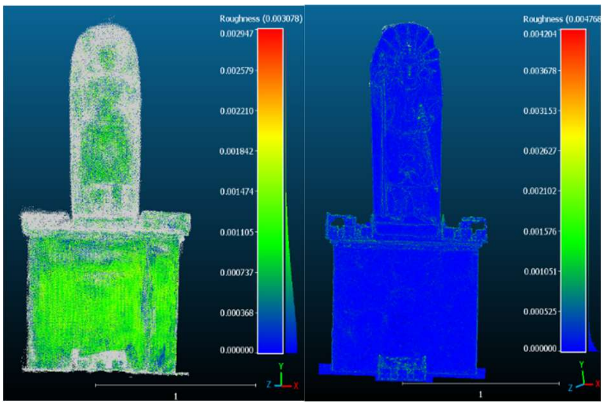


Figure 8: roughness test for (left) CRP (right) IPL

By comparing the density of the delivered point clouds models, CRP has resulted in a denser coverage than IPL. Point clouds densities are computed based on the number of neighbors of each point, using Cloud Compare software. The CRP achieved higher density median (26.59) than individual point clouds of IPL (22.89). The results of the comparison are outlined in Figure (9) when fitted to the Gaussian distribution function.

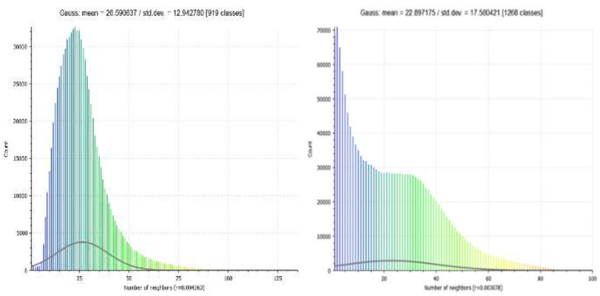


Figure 9: Histogram of the number of neighbors. (a) CRP (b) IPL.

producing a 3D model of point clouds using CRP started from the capture and then processing (alignment, meshing, texturing, filtering) took a time of 20 minutes, while one minute is enough time to produce a point cloud directly using IPL using the Sitescape application, meaning that IPL is 20 times faster than CRP. Both methods are considered low-cost in documenting and preserving. The iPhone 13 Pro Max was used in both methods, and its price is estimated at $1,200. Table 3 showe the final comparison for IPL and CRP methods.

Table 3: comparison result for IPL and CRP

	IPL	CRP
no. of scans /photos	1 scan	114 photos
program used	sitescape	reality capture
no. of points delivered	1,605,848	843,588
RMSE	0.011044m	0.000669m
Std.	0.4mm	0.2mm
time	1 minute	20 minutes
cost	1200 $	1200$

6. Conclusion

The performance evaluation of the iPhone 13 Pro Max LIDAR has led to several conclusions in this research . Applications using 3D cloud-based Lidar technology have shown superior speed and greater design adaptability compared to 3D mesh-based applications as they require additional processing time after laser scanning, while 3D cloud-based applications require no processing. Data obtained from 3D mesh applications also undergoes a filtering process to enhance data smoothness and reduce noise. However, this process results in important information being lost in the resulting model.

An important factor to consider is the file size, as some applications, especially those that rely on 3D mesh technology, may stop working if the file is too large. Also, the use of a stabilizer is crucial in this study to mitigate sudden movement, given the high sensitivity of the iPhone's lidar sensor to rapid movement.

In SGB CRB showed an advantage in terms of resolution and accuracy, where the 3D model clearly shows its fine details, unlike IPL where the resolution was not sufficient to show the details of the 3D model. When it comes to time, IPL significantly reduces the amount of time required compared to CRP. In the SGB case study, the IPL procedure required only 1 minute, but the CRP procedure took 20 minutes. The IPL has a fee of $1,200, which covers the paperwork, and the same applies to the CRB

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Appendix

The following tables represent the local coordinates on which the analysis was performed.

Table A: IPL error (ΔX(m), ΔY(m), ΔZ(m)).

NO	IPL			TOTAL STATION			Δ		
	E	N	Z	E	N	Z	ΔE	ΔN	ΔZ
2	79.8953	71.7648	29.2874	79.8907	71.7663	29.2967	-0.0046	0.0015	0.0093
3	79.7767	71.7349	29.288	79.7819	71.7286	29.2984	0.0052	-0.0063	0.0104
5	79.1678	71.5064	29.2901	79.1878	71.5128	29.2988	0.02	0.0064	0.0087
6	79.0732	71.4686	29.2896	79.087	71.4795	29.2963	0.0138	0.0109	0.0067
8	79.5707	71.5007	28.4959	79.5675	71.5008	28.4797	-0.0032	0.0001	-0.0162
9	79.4687	71.4644	28.4963	79.4645	71.4665	28.4822	-0.0042	0.0021	-0.0141

Table B: TLS error (ΔX (m), ΔY (m), ΔZ (m)).

NO	CRP			TOTAL STATION			Δ		
	E	N	Z	E	N	Z	ΔE	ΔN	ΔZ
2	79.8892	71.767	29.2967	79.8907	71.7663	29.2967	0.0015	-0.0007	0
3	79.7791	71.7291	29.2978	79.7819	71.7286	29.2984	0.0028	-0.0005	0.0006
5	79.1877	71.5138	29.2985	79.1878	71.5128	29.2988	0.001	-0.001	0.0003
6	79.087	71.4796	29.2969	79.087	71.4795	29.2963	0	-0.0001	-0.0006
8	79.5666	71.5006	28.4789	79.5675	71.5008	28.4797	0.0009	0.0002	0.0008
9	79.4658	71.4661	28.4803	79.4645	71.4665	28.4822	-0.0013	0.0004	0.0019

دراسة في توثيق التراث الثقافي باستخدام أجهزة الليزر المدمجة في الهواتف المحمولة

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الخلاصة – هناك حاجة لمزيد من التوثيق والبيانات الكمية حول القطع المعمارية والثقافية، خاصة بالنظر إلى الحالة المتدهورة لبعض الأصول التاريخية والمعالجات المطلوبة لها. في هذه الظروف، من الضروري الحصول على توثيق متري للتاريخ الذي يتم التحقيق فيه من أجل فهم الأصول بشكل شامل ومساعدة المهندسين والمعماريين في عملية التوثيق. كثيرا ما ترتبط تقنيات الحصول على البيانات ثلاثية الأبعاد، مثل النهج التصويري، بتكاليف عالية. وبدلاً من ذلك، قد يتطلب ذلك استثمارًا كبيرًا للوقت والجهد، مما يدفع المستخدمين إلى استكشاف حلول فعالة من حيث التكلفة تتيح لهم تحقيق مستويات الدقة المطلوبة. وفي الآونة الأخيرة، تم تطوير المعدات والعمليات الجيوماتيكية لتحسين الكفاءة والفعالية من حيث التكلفة في مسح الأصول الثقافية. قامت شركة Apple بدمج مستشعر LiDAR في منتجاتها، مما يتيح إنشاء نموذج ثلاثي الأبعاد. يهدف هذا البحث إلى تقييم دقة هذا المستشعر وعمليته في إنتاج صور ثلاثية الأبعاد للتحف الثقافية. تستكشف الدراسة قدرة iPhone Lidar (IPL) في الحفاظ على التراث الثقافي، وتفحص العوائق والصعوبات المحتملة التي قد تتطور، وتقيم فعاليتها في مجالات معينة. لتقييم دقة كل تقنية، تم إجراء مسح لدراسة الحالة باستخدام القياس التصويري قريب المدى (CRP) وiPhone 13 pro max، مع رصد أهداف اصطناعية مؤكدة بواسطة Total Station (TS). أشارت النتائج إلى أن جذر متوسط مربع الخطأ (RMSE) لـ IPL كان 8 مم، بينما كان لـ TLS 3 مم. يتمتع مستشعر الليدار بقدرات مسح سريعة بتكلفة رخيصة نسبيًا مع الحفاظ على مستوى مقبول من الدقة. ومع ذلك، لا ينبغي اعتباره بديلاً لـ TLS، لأن الأخير أداة لا غنى عنها لجمع البيانات على مسافات أوسع. وأسباب ذلك هي دقة المستشعر، وقدرته على تغطية المساحة الرأسية، ونطاقه المحدود الذي يبلغ حده الأقصى 5 أمتار. ومن المتوقع أن تخضع مواصفات المستشعر لتحسينات وتطورات إضافية، على الرغم من هذه القيود. أداة حاسمة لجمع البيانات على مناطق واسعة.

الكلمات الرئيسية —– جهاز IPhone Lidar (IPL)، ليزر سكان، المسح التصويري عن بعد، توتال ستيشن، RMSE، ثلاثي الأبعاد