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COMPARISON AND EVALUATION OF TLSs AND MOBILE LiDAR SCANNERS FOR MULTI-SCALE 3D DOCUMENTATION OF CULTURAL HERITAGE

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ABSTRACT:

Field documentation of archaeological sites and built heritage by point-cloud is very effective in yielding arbitrary 3- dimensional shapes of various objects. There are several options for methods and devices such as TLSs, Mobile scanners, and SfM-MVS-based CRP. These are based on different technology, mechanism, and algorithm. Therefore, it is difficult to compare their precision, resolution, and measurement error in the same manner under practical conditions rather than catalog specification. The authors plan and carry out a field experiment of 3D point-cloud measurement in an archaeological site to obtain sample data for comparison between methods and devices under controlled conditions. Through comparative analysis, we evaluate character and advantage, as well as comparative measurement errors between methods and devices, then argue the combined use of different methods and devices under the "Multi-scale 3D scan strategy".

1. INTRODUCTION

3D point-cloud measurement is effective in the documentation of cultural heritage. However, there are various methods and devices which yield data with different precision and resolution with different errors. For example, Terrestrial LiDAR Scanners (TLS) is precise and stable due to fixed station point, while Mobile LiDAR Scanner (MLS) is more flexible but unstable due to continuous movement during measurement. Another important factor is resolution and quality of texture (when it is available) which represent the detail of objects. In this regard, SfM-MVS-based Close-range Photogrammetry (CRP) has the advantage. But CRP requires externa references or aligned to other point-cloud acquired by direct measurement like LiDAR scanners. For more effective operation, it is necessary to evaluate the character of different methods and devices in actual field conditions. Therefore, we planned and carried out a field experiment in the archaeological excavation site to obtain sample data under controlled conditions with different methods and devices.

2. FIELD

The experimental field is in the Nishiura-Ashiho-Hayashi stone quarry site in Numazu City, Shizuoka Prefecture, in the Pacific coastal area of central Japan (fig.1). The site is a stone quarry which is situated in a hilly sequence at the north-western part of Izu Peninsula. Its geological setting is the Quaternary Andesite and Basaltic-Andesite formation (Sugiyama et al., 2010). These volcanic rocks are common in the material of the stone wall of the late Medieval and the early Edo Period (in the late 16th and the early 17th Centuries CE). Quarried stones from the site are considered to be used in Sunpu-Jo Castle (Shizuoka City) and Edo-Jo Castle (Tokyo Metropolis).
The excavation is operated by Shizuoka Prefectural Archaeological Centre between November 2022 and January 2023, as a preventive investigation before road construction. The excavation area is about 450 square meters in 35.014950N, 138.834987E (at the center) on a slope between 46.6 and 50.3m in altitude above Sea level. The main feature is remaining stones with aligned wedge holes during quarrying and transportation at the time.

Figure 1. Location of the site.

3. METHDOS AND DEVICES

3.1 The setting of the experimental field

The focal area for the experiment is about 250 square meters with a 5m relative height within the excavation field. focal area of experimental comparison is set at 8 by 4 meters with 5 reference points and 2 verification points (Fig.2). Both reference and verification points are measured by Total Station (TOPCON GT-1005).

3.2 Devices and settings

For the experimental measurement survey, 2 TLSs and 2 MLSs are employed. TLSs are TOPCON GLS-2000 and Leica geosystems BLK-360. MLSs are Leica geosystems BLK2GO, and Apple iPhone 12 pro. Scaniverse App is selected for iPhone Mobile LiDAR Scan. Scan pitches are represented in Table 1 while specifications are in Table 2.
CRP is implemented by Agisoft Metashape on Windows 10 Pro. Photos are taken by SONY ILCE7C digital still camera with a SEL2470Z lens (fixed at 24mm). 446 photos are shot on the ground without a tripod. 21M pixels JPEG images are input for processing. A dense point-cloud is built in Ultra High quality with middle depth filtering while alignment is carried out with the Highest accuracy.

Device	setting
GLS-2000	12.5mm at 10m
BLK360	6mm at 10m
BLK2GO	(average 6.4mm)*
iPhone 12 pro +Scaniverse	3mm
Agisoft Metashape	Ultra High**

* average density calculated from the result
** Quality of building dense-cloud procedure

Table 1. Scanning settings.

Device	GLS2000	BLK360	BLK2GO	iPhone12Pro	3D photogrammetry (SONY ICLE-7C)
					
Device size	W=293mm,H=412mm,D=228mm	H=165mm, r=100mm	H=279mm, r=80mm	W=71.5mm, H=147.5mm,D=7.85mm	W=124.0mm,H=71.1mm,D=59.7mm
Weight	10kg	1kg	0.78kg	0.21kg	0.51kg
Scan Range	350m	60m	25m	5m	∞
Scan Speed	120,000points/s	360,000points/s	420,000points/s	-	-

Table 2. Specification of devices

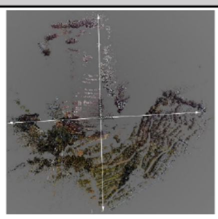
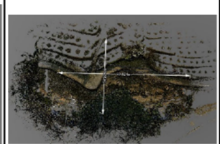
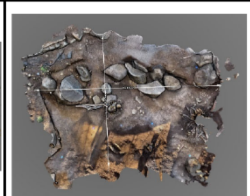
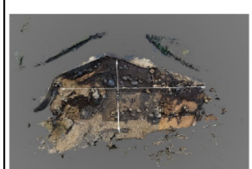
4. RESULTS OF DOCUMENTATION

4.1 Scan Range

The actual field scan range of each device is represented in Table 3. GLS-2000 shows the widest area about 266m by 261m while the iPhone LiDAR scan shows the smallest area about 10m by 7m. BLK-360 and BLK2GO show intermediate results (Table 3; Figure 2).
However, it must be noted that these are not effective scan ranges but are maximum reach in given conditions. Larger TLS, such as GLS-2000, shows overperformance against the relatively small area. On the contrary, the scan range of both MLSs and CRP can be controlled by work procedure. This must be considered to evaluate working performance per time. Another factor for consideration is the density of the point-cloud, especially in the focal area. In this regard, the iPhone LiDAR scan shows the highest performance while GLS-2000 shows a sparser result.

4.2 Work time

The working time of each device is also represented in Table 3. iPhone LiDAR scan shows the fastest performance in 22 minutes, while other LiDAR scanners spend about 1 hour for output after processing. CRP shows the longest working time, about 21 hours. But it must be noted that the working time for field documentation is about 30 minutes.
The estimated work time per 20 and 10000 square meters of each device and method are represented in Table 4. This would be a quick reference for further application.

Result					
					
Max Range	266m x 261m	34m x 46m	34m x 59m	7m x 10m	14m x 26m
Total Work Time	0:55	1:05	1:05	0:22	20:58
GCP setting	0:10	0:15	0:10	0:15	0:15
Scanning	0:35	0:30	0:25	0:04	0:15
Processing	0:10	0:20	0:30	0:03	20:28

Dense Cloud only (no mesh, no texture)

Table 3. Scan range and work time of each device

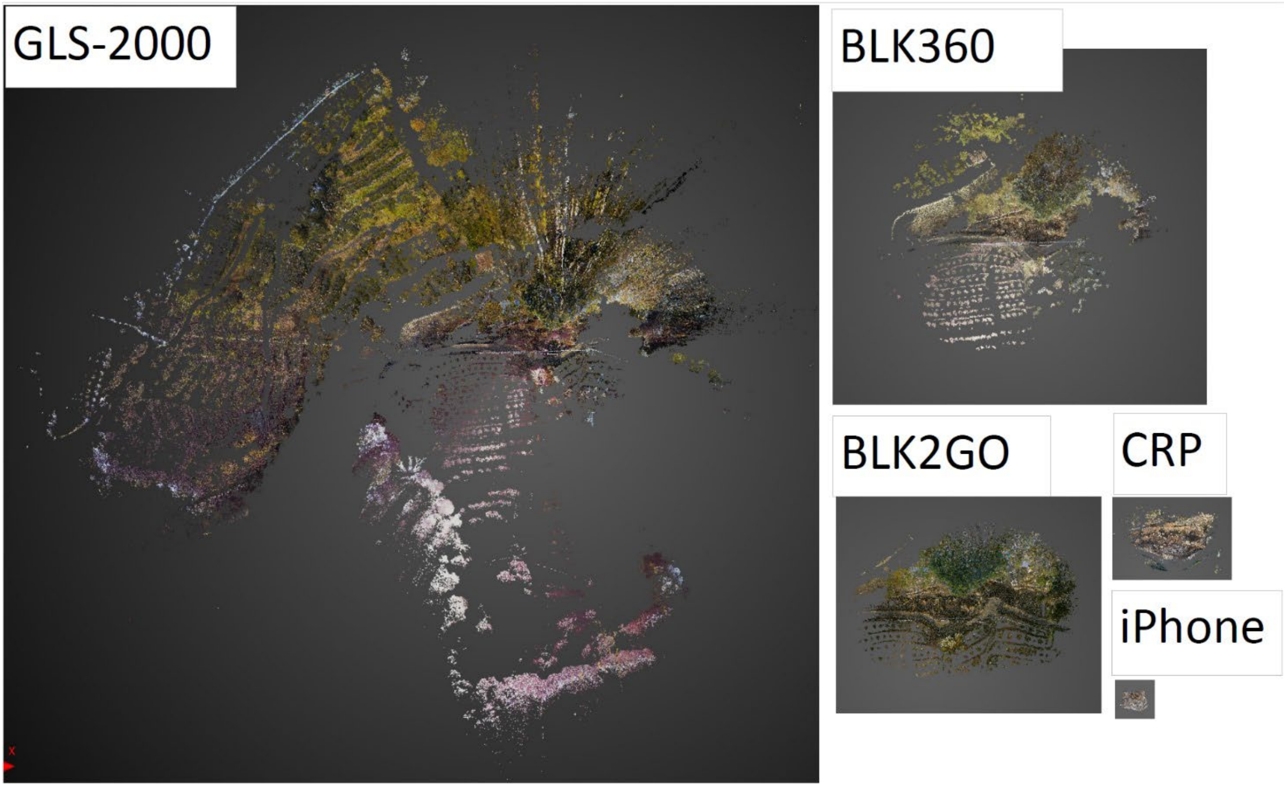


Figure 2. Scan results in same scale.

4.3 Representativity

In the field of archaeology and cultural heritage management, representativity is another important factor for documentation as same as accuracy and precision. More detailed documentation provides richer information. In this regard, CRP is the best way with high-resolution color texture graphics when mesh and texture are built upon dense point-cloud or depth maps. Also, iPhone LiDAR scan can provide high-resolution color texture by installing a high-quality camera. On the contrary, other LiDAR scanners are behind these 2 methods (Figure 3).

Figure 3. Comparison of resolution of point-cloud and representativity (left: iPhone LiDAR scan, right: GLS-2000)

5. EVALUATION OF ERROR

5.1 Method and Procedure of error evaluation

3D point-cloud yielded by different devices and methods are aligned by Helmert Transformation with 5 reference points (SU7~11 in Figure 4) and examined errors with verification points. Standard deviation: σ of residual errors after transformation is between 0.002 and 0.004m. However, scan pitch (or point-cloud density) and covered area are not the same between different methods and devices. It is not equal even by the same method and device at different timing. In cases of LiDAR scan, it depends on the condition of projection and detection of reflection in each timing, while dense point-cloud reconstructed by CRP relies on different algorithms and calculations. It is impossible to compare each other directly.

Therefore, standardization of the point-cloud is required at first. It is carried out with KENTEM SiTE-Scope software by creating TIN with minimum height (Z value) point within 0.1m meshes. Then Z axis error is examined at 20 random points in and around the focal area (Figure 4). X-Y-Z coordinates of these points are measured by Total Station in the field as same as reference and verification points (see 3.1). The difference between the Z values of each random point and the center of the mesh, which is corresponded to the random point, is measured as an error at the point. The total error is summarized and compared by devices (Table 4,).

5.2 Results

While the iPhone LiDAR scan shows a total error σ=0.014m, others show a more precise result (σ=0.005~0.008m). These can be indices of comparative measurement error of each device and method. TLSs, BLK2GO and CRP show mm order measurement errors. iPhone LiDAR scan shows a relatively large error in cm order.

Figure 4. Random points for examination of errors in Z axis

Results and Evaluation	Terrestrial Scanners		Mobile Scanners		CRP
	GLS-2000	BLK360	BLK2GO	iPhone	
Error					
Max	0.012	0.015	0.019	0.031	0.000
Min	-0.019	-0.016	-0.014	-0.027	-0.020
σ	0.007	0.006	0.008	0.014	0.005
Evaluation					
Representativity	Low	Low	Middle	High	High
Point-cloud density	Low	Middle	Middle	Middle	Middle
Scan range	Large	Middle	Middle	Very small	Small
Work time					
$20m^2$	15 min	6 min	3 min	4 min	10 min**
$10000m^2$*	90~120 min	240~300 min	40 min	(impossible)	(impossible)

* calculated from the experimental result
** Photo capturing, excluding post-process time

Table 4. Results and Evaluation of Experimental Survey

6. DISCUSSION

TLSs are stationed in a basement (tripod). Therefore, measurement condition is more stable than MLSs and CRP. In this regard, point-cloud yielded by TLSs can be reference data. Meantime, TLSs is less eligible to document arbitrary undulating surface, because its perspective is fixed in each measurement. During experimental surveys, this is caused by leaving holes behind or beneath rocks, and other 3-dimensional features which obstruct laser irradiation and reflection (Figure 3). To avoid such defectiveness, frequent moving of station points is necessary, and it is affected work time.

On the contrary, MLSs and CRP cover the undulating arbitrary surface and represent more detail because the device can be continuously moving along the arbitrary surface of the object(s). This is sufficient for archaeological features and other cultural heritage which basically have complex 3-dimensional forms. However, such mobility during measurement is negatively affected by precision.

Our result shows that MLS (BLK2GO) and CRP (on the ground without a tripod) present good performance. Their precision is comparable to TLSs. However, the resolution and representativity of MLS (BLK2GO) are less than CRP, while CRP needs much time for processing. In contrast, iPhone LiDAR scan can provide high resolution and representativity like as CRP within a short time, but its precision is inferior to other methods and devices.

With this evaluation, we argue that the combination of devices and methods is more effective and efficient for field documentation of archaeological and cultural heritage objects. For example, TLS is the best for scanning large areas at one time, while MLSs and CRP can be employed for covering the detail of necessary parts of complex 3-dimensional features. While recent studies show effectiveness of iPhone (iPad) LiDAR scan (Lose et al., 2022; Vacca, 2023). But it is required to evaluate measurement error. In this regard, documented data by TLS can be treated as a reference to other methods and devices. Of course, UAVs and other gears can be employed for further additional documentation. We define this as the "Multi-scale 3D scan strategy". The combination of TLS, CRP, and iPhone LiDAR scan can achieve this with less than 20mm measurement error.

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