3D PHOTOGRAMMETRY MODELING FOR SAFETY MONITORING OF FORTRESS WALLS

S.J.Choi[1], J.Y.Lee[2], S.J.Yoo[3], S. H. Kim[1]

[1] Graduate School of Cultural Heritage, Korea National University of Cultural Heritage, South Korea – (20222103, 20222032)@nuch.ac.kr

[2] Korea National University of Cultural Heritage, South Korea - leejaeyong82@nuch.ac.kr

[3] Hyperspectral Strategic Team, GEOSTORY Co.Ltd., South Korea - sjongyu@geostory.co.kr

KEY WORDS: Unmanned Aerial Vehicle Photogrammetry, Terrestrial Laser Scanning, Cultural Heritage Management, Monitoring, Structural Safety Diagnosis, Displacement, Heritage Documentation

ABSTRACT:

In the monitoring to prevent collapse or tipping in the structure of linear-shaped fortress walls, the record of shapes like slope or protrusion is very important(Jo and Hong, 2019). As the way to record the shapes, laser scan or photogrammetric technology is employed. A laser scan that has to install several points of measurement has a limitation in recording them if the terrain is undulating, or the structure becomes huge. Photogrammetry has a shortening effect in terms of cost and process(Kim, 2020) compared to that.

This study examined a measure for producing a 3D mesh model with aerial and ground photography for fortress walls. In addition, this study tested if it would be possible to monitor the slope and protrusion, etc. of fortress walls. This study tested the accuracy of the model produced with photogrammetry to use in the diagnosis and monitoring of the structural safety of fortress walls.

The research subject was Korea's cultural heritage, Seosan Haemieupseong Fortress, and a model was produced for the section about 100m of the fortress walls.

The positional accuracy, elevation/section accuracy, LOD, and texture joint precision of two models (Model A & Model B) produced with photogrammetry and laser scan were compared.

This study revealed that the model produced at LOD Level 4 would be effective for monitoring the displacement since it could measure the shape, curvature, and slope of stones of the fortress walls.

1. INTRODUCTION

It is necessary to develop measures to repair and preserve the cultural heritage by frequently monitoring it. In particular, the displacement and damage including collapse and overturn are likely to occur over time in the structures such as fortresses or Eupseong, due to the earth pressure or the inflow of running water, so it is essential to frequently check the safety of them. The Korean building cultural properties are regularly examined every three or five years, for the safety monitoring of them. They are designated as the intensive control lists, if more systematic examination is required because serious faults are found, and then, the precise measurement of them is conducted by using the visual examination and equipment.

It is very important to record several figures including slops and projections, in monitoring long fortress structures(Jo and Hong, 2019). A 3D model established allows to do the efficient and dimensional monitoring on them. Although the laser scanning commonly used for producing the 3D model for the cultural heritage can acquire high-precise data, it needs to takes long time to acquire the data and undergo the post-processing process. It is necessary to repeat the periodical measurements, to discover the displacement, but there is a limit in comparing and discovering the displacement by using big point cloud data. In addition, it is also difficult to apply scanners to the fortress walls located at steep terrain or cliffs and acquire the data, as the blockade occurs, and therefore, the production costs increase. It becomes possible produce an efficient 3D model using the digital photogrammetry, as the drone shooting can be recently possible. The accuracy is also actively examined. The digital photogrammetry is effective in reducing expenses and working hours and its errors is lower as the GSD less than 3cm(Kim, 2020), compared to the laser scanning. O Junyeong et al.(2017) proved that the digital photogrammetry is more useful than the laser scanning by applying both techniques to a rock cliff Buddha. Kimg Seonghan et al.(2019) noted the potential to acquire the 3D model of fortress walls which persons cannot easily access, through the digital photogrammetry using drones and the laser scanning as a short monitoring method, it did not examine the usability of it as the long-term technology.

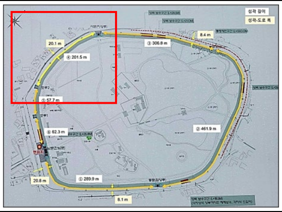
This study analyzed the accuracy and the precision of the 3D model of complex and long fortress walls among the Korean cultural heritage, which was produced with the digital photogrammetry using drones. It examined whether it is possible to regularly and accurately diagnose the safety conditions of fortress walls, such as the slopes and projections, by using the model established through the digital photogrammetry.

2. STUDY AREA AND METHOD

This study examined the Seosan Haemi Eupseong, among the Korean cultural heritage, which was constructed in 1491 (Figure 1). Eupseong is located at Seosan-myeon, Chungnam and its whole circumstance, internal area are 1,800m and 196,381㎡, respectively. The average height of the fortress walls is 4.9m, and the top width is about 2.1m and the soil is slantingly accumulated at the inside of the fortress walls(Kim et al., 2016). About 23-26 facing stones are accumulated on the fortress walls and the size of them gradually increase from the bottom to the top.

It selected the target area by considering the presence of the neighboring obstacles and hurdles, the topography for the drone shooting and the safety in shooting it(Figure 1). It produced a 3D model by selecting the interval of about 100m, from the west gate to Poru(artillery bastions) along the whole fortress walls, and analyzed the accuracy and the precision for about 2m, the part of the interval. It collected the data from Jun., 08 to Jun., 11 in 2021.

a. Panoramic View (Cultural Properties Administration)



b. Ground Plan (Seosan-si)

Figure 1. Study Site and Area

This study was conducted by surveying the ground control point and the control point, followed by collecting the 3D data based on the laser scanning and the digital photogrammetry, and then analyses on the unification of two models, and the accuracy and the precision of the digital photogrammetry 3D model.
The laser scanning commonly used for producing 3D models, which is a measurement for determining the relative position of an observation point, by using the time difference and the rotation angle, calculated while infrared laser reflects off the observation point and returns to its original point, can collect high precise data.

There are smallest errors between The laser scanning outcomes and real objects, so the analysis on the accuracy used the 3D models produced from the laser scanning and the digital photogrammetry as the control and the comparison, respectively.

3. RESULT AND DISCUSSION

3.1 Ground Control Point and Control Point Surveying

This study surveyed a total of 11 ground control points (one ground control point per 0.01㎢) with the position accuracy less than 3cm, by using Leica GS08+, based on VRS(Figure 2). It selected the areas that can be clearly distinguished by using topographical features such as manholes, paving blocks, etc., and those with the visual field more than 45° from the ceiling, to prevent the distortion during the drone shooting.

a. Ground Control Pont Surveying

b. Equipment Used

Figure 2. Ground Control Point Surveying

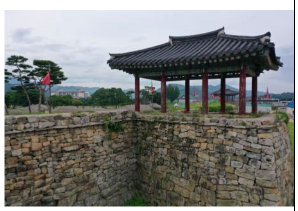
The control point surveying was conducted in the same way in which the ground control point surveying was conducted. Then, the control points were used in analyzing the accuracy. The amount of the control points should be at least 1/3 of the amount of the ground control points, according to the UAV-based public surveying guideline. This study surveyed 9 control points against 11 ground control points, to verify the accuracy of precise positions.

3.2 Collection of 3D Data

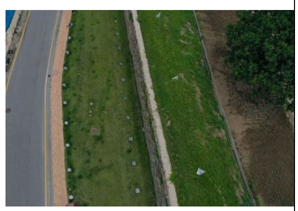
It used the DJI Mavic Air and DJI Mavic 2 Pro, equipped with GPS, for the digital photogrammetry. The data were collected by initially making the shooting plan, followed by checking the drones and the camera performance, and the, taking vertical and oblique shots in the air, taking horizontal and oblique shots at the lower altitude, taking occlusion areas and examining and arranging the shooting data.

It acquired 1,227 photographs by taking vertical and oblique shots in the air, at the altitude of 25m, given the height of the fortress walls. It compensated the curved and occlusion areas of the fortress walls, by taking horizontal and oblique shots at the low altitude. It acquired 297 photographs by manually operating a drone to taking vertical shots of the point 10 m away from the fortress walls at the low altitude (3, 5, and 7m height), with the cameral angle of about 45°. It acquired a total of 110 photographs about the occlusion area by adjusting the set points such as the camera exposure, ISO, etc., so a total of 2,658 photographs were used in the analysis (Figure 3). It spent about 7 hours to taking shots.

It planned the longitudinal overlap of the shooting more than 80% and the crossing overlap of it more than 70%, to minimize the occlusion area and matching errors, given the area of Eupseong, and took shots with the resulting overlap of 80% or 85-90%(Table 1).



a. Vertical-Oblique Shot



b. Vertical Shot

c. Horizontal Shot

d. Ground-Occlusion Shot

Figure 3. Digital Photogrammetry

Division	Photographs (sheets)	Altitude (m)	Overlap (%)	Flying Speed (m/s)	Shooting Modes
Vertical-Oblique	1227	25	80	0.6	Auto
Vertical	1024	25	80	0.8	Auto
Horizon	297	3, 5, 7	85-90	0.8	Manual
Ground-Occlusion	110	-	85-90	0.8	Manual

Table 1. Information of Digital Photogrammetry Data

It used FARO Focus 3D X330 HDR for the razer scanning. It scanned the top, facade and the rear of the fortress walls, given the height of them and the occlusion area (Figure 4). The it collected a total of 51 scanned data sets consisting of 18 data sets on the top, 17 data sets at the facade and 16 data sets at the rear, and there was the interval from 5 to 7 cm between two scan points (Table 2). It took about 13 hours to correct the data.

a. Data Collection Position Map

b. On Top of Fortress Walls

c. Façade of Fortress Walls

d. Rear of Fortress Walls

Figure 4. Laser Scan Data Collection Position Map and Field

Division	Number of Data Sets(Sites)	Interval(m)
Top	18	5-7
Facade	17	5-7
Rear	16	5-7

Table 2. Information of Laser Scan Data

3.3 Production of 3D Model

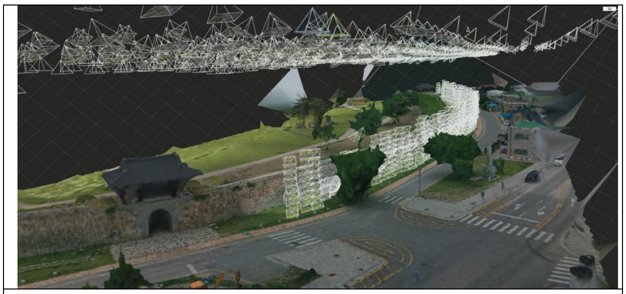
The digital photogrammetry-based 3D model production was conducted by inputting shot images, followed by matching the ground control points, and then, the aerotraingulation and the post-processing. It used the Agisoft Metashape for the 3D model production.

It inputted aerial and ground images shot by drones and the exterior orientation parameters acquired from GPS applied to the drones. The exterior orientation parameters, which produce the posture values of drones by using the geometric conditions of the drone shooting, and the X, Y and Z position and posture information of drones as Omega, Phi and Keppa, can be used the initial ones for establishing the model. It tried to match with the images into which the exterior orientation parameters are inputted, by using the WGS84 ellipsoid coordinate system set in surveying the ground control points.

The aerotriangulation was conducted by the cameral calibration, image matching and he bundle block adjustment. It automatically matched with overlapped images and removed the images with high automatic tie points and RMSE between images(Figure 5).

The production of a 3D model using the laser scanning was conducted by the matching of the scan data, followed by the merging of them., and the, the post-processing of them. It used the Cyclone and Geomagic Design X, for the production of it. It matched with the whole scan data based on the common control points of more than three points and merged them into a model (Figure 5).

For the efficiency, it removed the data outside of this study scope, in the post-processing of two models.



a. Photogrammetry Model (Model A)

b. Laser Scan Model (Model B)

Figure 5. Production of 3D Model

3.4 Unification of Two Models

It unified the forms and coordinates, to compare two models. It abstracted Model A and Model B as the same point cloud data, through the Reality Capture and the Cyclone, respectively, to minimize the errors occurring in comparing them. Then, it makes two model have the same coordinates, by applying the absolute coordinates of the model A to the model B, based on the cloud comparison (Figure 6).

a. Model A

b. Model B

c. Unification of Two Models

Figure 6. Unification of Two Models

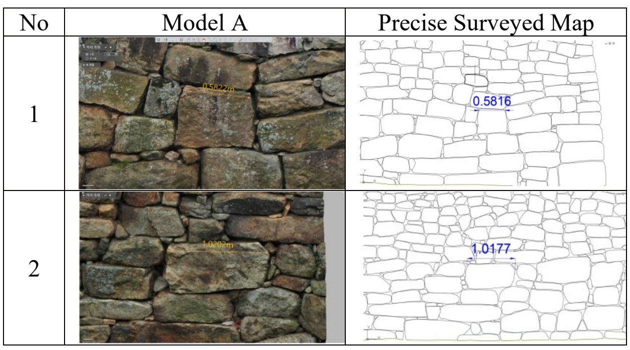
3.5 Analysis on Accuracy of 3D Model Using Digital Photogrammetry

3.5.1 Accuracy of Positions: It compared a total of nine control points acquired with VAR, for the model A. It calculated the differences in the coordinates between the control points of the model A and those surveyed. The findings show that the minimal, the maximal and the average error of the coordinates were 0.008m, 0.037m and 0.023m, respectively, with the standard deviation of 0.009m and the RMSE of 0.025m, indicating the very high accuracy (Table 3).

No	Control Point (m)			Model A(m)		
	X	Y	Z	X	Y	Z
1	159497.223	457236.247	32.903	159497.206	457236.264	32.866
2	159506.266	457284.171	32.809	159506.242	457284.184	32.792
3	159539.339	457344.411	32.571	159539.308	457344.445	32.563
4	159568.808	457377.960	32.480	159568.771	457377.986	32.460
5	159467.707	457225.224	32.350	159467.709	457225.190	32.314
6	159474.714	457273.948	32.003	159474.704	457273.942	32.029
7	159483.004	457317.497	31.938	159483.027	457317.466	31.968
8	159510.648	457365.672	31.779	159510.686	457365.665	31.817
9	159529.398	457405.901	31.637	159529.435	457405.892	31.626

Table 3. Position Coordinates of Control Points

3.5.2 Facade Accuracy: It compared the differences in precise surveyed maps between the model A and 「Seosan Haemieupseong Precise Survey and Structural Safety Diagnosis Project (4th)」(2016). The precise surveyed maps were created by collecting the point cloud data about the whole fortress walls with the 3D ground lidar technology.
The façade accuracy was conducted by initially producing the 3D mesh model based on the digital photogrammetry, followed by selecting fortress stones, and then, comparing the size of them. For a precise comparison of two data sets, it conducted a test by using the 3D mesh model, not in the form of point. It compared the width of fortress stones, by randomly selecting 10 fortress stones from the façade of the fortress walls. The results show that each of the average, the maximal and the minimal error was 1.40mm, 2.5mm and 0.2mm, respectively, indicating the high accuracy (Figure 7).



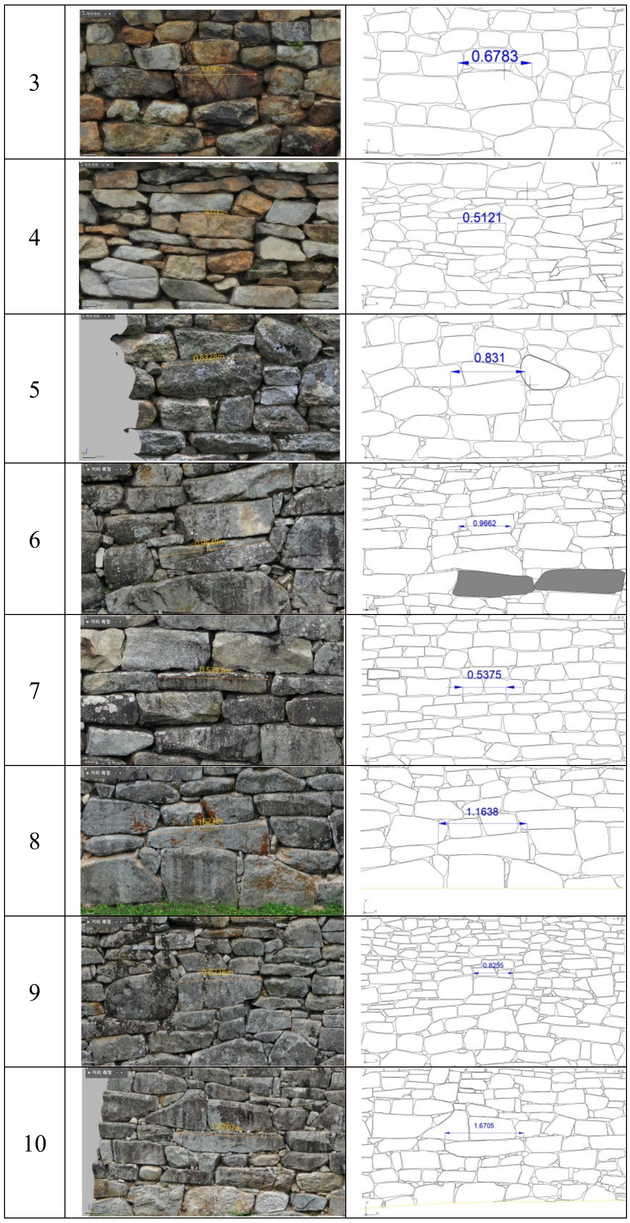
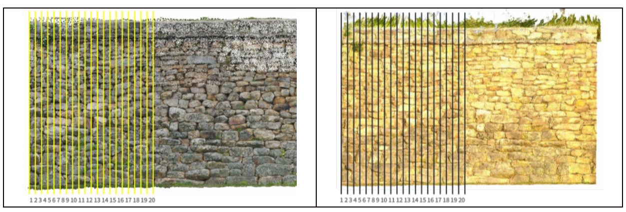
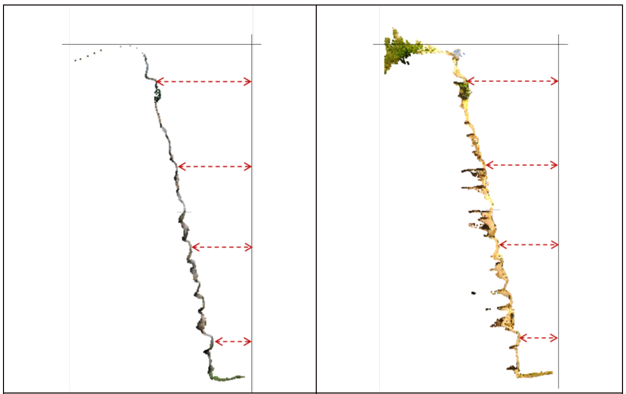


Figure 7. Analysis on Accuracy of Façade

3.5.3 Accuracy of Section: An analysis on the section accuracy was conducted by comparing the model A and B. It was conducted by initially selecting the intervals, demarcating the sections and analyzing the coordinates, for two models. It selected the interval of about 2m, which has the fewest joining error chased by shaded and has the densest points, based on the model A produced with the digital photogrammetry. Each number of the model A and B was 112,722 and 7,355,480, respectively, at the selected interval. It produced a total of 20 section maps at the 10cm gaps, within the selected interval (Figure 8).

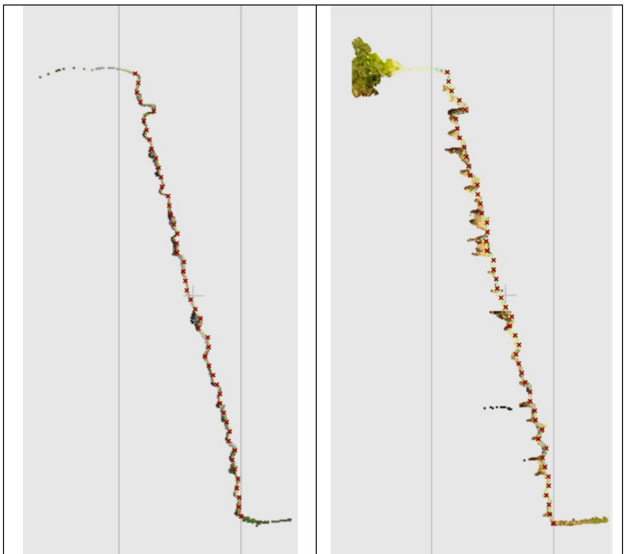




a. Model A | b. Model B

Figure 8. Selection of Interval and Demarcation of Sections

It compares the increases of Y with the differences in X, for 20 sections(Figure 9). It estimated a total of 50 difference in X, by equally dividing the sections at 0.1mcm gaps for the model A and B as follows: y=0, y=0.1m, y=0.2m, ··· , y=4.9m. It reviewed a total of 50 differences in X for 20 sections each in the model A and B.



a. Model A | b. Model B

Figure 9. Comparison of Positional Coordinate by Points of Sections

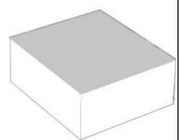
The results show that each of the average, the maximal and the minimal error was 0.013m, 0.062m and 0.000m, respectively, with the average RMSE of 0.263m, indicating that there is little difference between two models (Table 4).

No.	△X(m)	RMSE	No.	△X(m)	RMSE
1	0.062	0.591	11	0.008	0.149
2	0.013	0.336	12	0.013	0.135
3	0.012	0.230	13	0.007	0.119
4	0.007	0.170	14	0.000	0.289
5	0.009	0.239	15	0.003	0.306
6	0.013	0.288	16	0.019	0.308
7	0.001	0.188	17	0.030	0.322
8	0.005	0.250	18	0.023	0.321
9	0.015	0.304	19	0.003	0.267
10	0.011	0.156	20	0.014	0.311
Mean				0.013	
RMSE				0.263	

Table 4. Analysis on Section Accuracy

3.6 Analysis on Precision of 3D Model Using Digital Photogrammetry

3.6.1 LOD (Level of Detail): To evaluate the 3D modeling LOD of the model A, it verified the LOD of 3D building data and the visualization information production criteria in the 3D Korea Land Spatial Information Establishment Rule (National Geography Information Institute Notification No. 2016-146, Implementation, Jul., 01, 2019) (Table 5).

Large Division	Data of 3D Building	
Middle Division	Residential and Non-residential Building	
Small Division	General Houses, Apartment Houses, Public Institutions, Industrial Facilities, Cultural Education Facilities, Medical Welfare Facilities, Service Facilities, and Others	
LOD	Criteria of Production	Examples of Production
Level 1	-Block Form -Roof Surface with Monotone Texture -Unproduction of Vertical Projecting Part and Depressed Part -Monotone, Colorful or Virtual Image Texture	
Level 2	-Blocks or United Blocks -Roof Surface with Colorful or Orthimage Texture - Unproduction of Vertical Projecting Part and Depressed Part -Virtual Image and Real Image Texture	
Level 3	- United Block Form -Production of Roof Structure (Slope) -Production of Vertical Projecting Part and Depressed Part -Virtual Image and Real Image Texture	

Level 4	-3D Real Model -Production of Roof Structure (Slope) -Unproduction of Virtual/Horizontal Projecting Part and Depressed Part	

Table 5. LOD of 3D Building Data and Criteria of Producing Visualization Information

The slop and projecting and depressed parts of the fortress walls were expressed, and the real image texture was also embodied for the model A, indicating that it satisfies the criteria of the LOD Level 4 specified in the rule.

3.6.2 Joining Precision: A Test of the texture joining precision for the model A shows that each resolution of the vicinity of fortress walls and the fortress walls was 6mm/pixel and 0.12mm/pixel, respectively, indicating that the resolution of the fortress walls was higher than that of their vicinity(Figure 10).

The number of overlapped images was up to 810 for the fortress walls, while aerial shots of their vicinity were often taken, so the number of their overlapped images was less than 810. In addition, multiangle shots of the vicinity of the fortress walls were not taken, so errors occurred or the resolution was low.

Not only the aerial shooting using drones but also the shooting from various angles, including vertical and oblique shooting and the occlusion area shooting are required for the large-area cultural heritage, such as Haemieupseong, and it is effective to use both automatic and manual shooting modes in producing the 3D model with the high joining precision.

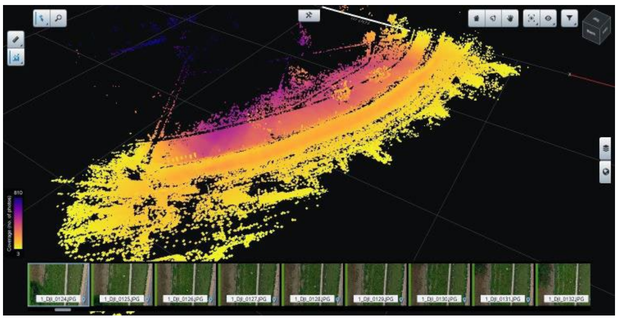


Figure 10. Joining Precision of Model A

4. CONCLUSIONS

This study established the 3D model for the fortress walls, the large-area cultural heritage, through the laser scanning and the digital photogrammetry using drones. It was found that it is effective to use the aerial shooting, the shooting from various angles, including vertical and oblique shooting and the occlusion area shooting, and both automatic and manual shooting modes, for increasing the precision of the models during the digital photogrammetry.

The accuracy and precision of the digital photogrammetry were as good as those of the laser scanning. The digital photogrammetry was expected to be effectively used for the displacement survey monitoring which helps quantitatively understand the form, curve, slop, etc. of the fortress walls, as it could save more than five hours in collecting the data. It proved that the laser scanning commonly used for currently producing the 3D model can be replaced with the digital photogrammetry which is more efficient in terms of both cost and time, in monitoring the large-area cultural heritage such as the fortress walls for a long time. It would be possible to do the fast and efficient structural safety diagnosis monitoring on the large-area cultural heritage including the fortress walls, if the digital photogrammetry is used for it.

ACKNOWLEDGEMENTS

This research is supported 2021 Cultural Heritage Smart Preservation & Utilization R&D Program by Cultural Heritage Administration, National Research Institute of Cultural Heritage (Project Name: Multiple Integral Diagnosis Technology of Large-scaled Cultural Heritage , Project Number: 2021A01D02-001)

REFERENCES

Bouziani, M., Chaaba, H., & Ettarid, M., 2021, Evaluation of 3D Building Model using Terrestrial Laser Scanning and Drone Photogrammetry. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 46, 39-42.

Jo, Y. H., & Hong, S., 2019, Three-dimensional digital documentation of cultural heritage site based on the convergence of terrestrial laser scanning and unmanned aerial vehicle photogrammetry. ISPRS International Journal of Geo-Information, 8(2), 53.

Kim Jae-ung, 2020, A Measures to Implements the Conservation and Management of Traditional Landscape Architecture using Aerial Photogrammetry and 3D Scanning, Journal of Korean Institute of Traditional Landscape Architecture, vol. 38,no. 1, 77-84.

Oh, J.-Y., & Kim, C.-S., 2017, A Study on the Usefulness of Photogrammetry through 3D Recording of the Rock-carved Standing Buddha in Singyeong-ri, Hongseong. MUNHWAJAE Korean Journal of Cultural Heritage Studies, 50(3), 30–43.

Lee, InSu, LEE, Jae-One, Kim, Su Jeong, & Hong, Soonheon., 2013, Orhtophoto Accuracy Assessment of Ultra-light Fixed Wing UAV Photogrammetry Techniques. KSCE Journal of Civil and Environmental Engineering Research, 33(6), 2593–2600.