DEFORMATION MONITORING FOR HISTORICAL SITE USING CLOSE-RANGE PHOTOGRAMMETRY TECHNIQUE

Pei-An Lin, Yi-Hsing Tseng

Department of Geomatics, National Cheng Kung University,
No.1, University Road, Tainan City 701, Taiwan (R.O.C)
Email: annj9140@prs.geomatics.ncku.edu.tw; tseng@mail.ncku.edu.tw

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ABSTRACT: With the development of remote sensing technology, using optical sensors to record and preserve heritage sites have been widely used and well recognized at an international level. Different from the traditional recording method using hand-painting or plane table to do measurement, using non-invasive optical sensors like digital camera or laser/radar scanner can provide more realistic, accurate and precisely results. Digital recording documents are much easier to preserve and can be utilized in many other purposes like cross-comparison, monitoring of shape and colors, multimedia museum exhibitions, visualization, reconstruction, virtual/augmented reality applications and so on. LiDAR point cloud has real scale and high precision, but its color would be easily affected by weather, levels of brightness, and calibration of the mounted camera. The equipment is also heavy and expensive. The accuracy of image-based point cloud using digital camera is highly depended on the resolution of the images. The texture of 3D model using photogrammetry is more realistic. Digital cameras are also portable. On account of portability, the digital camera is chosen to record the heritage site.

This paper conducts a survey in the test field to simulate deformation using terrestrial LiDAR scanner, unmanned aerial vehicle (UAV) and handheld camera to observe movement of measuring points. Aerial images taken by UAV are georeferenced and the image quality is stable but the resolution is not higher than the handheld camera. Terrestrial images taken by handheld camera are easily affected by the photographer (e.g. blurry image because of vibration) and was needed to be given a real scale. Considering all pros and cons mentioned above, the LiDAR point cloud was used to check the accuracy of image-based point cloud by handheld camera and UAV. Through previous experiments, the testing method is feasible. The accuracy of image-based 3D models can achieve centimeter level precision. The high precision measuring results were used to conduct deformation monitoring and displacement observation. Then the accuracy of the 3D models will be analyzed using different kinds of remote sensing sensor data and each method' limitations will be reviewed as well. It can be expected that this can be used to apply deformation monitoring of large scale archaeological remains in the future.

INTRODUCTION

In this April, Notre-Dame de Paris got burned is definitely the most shocking news in 2019. This cathedral was built in 700 years ago and took almost 200 years to finish constructing, all of a sudden, was destroyed and caused tremendous losses. Luckily, prof. Andrew Tallon began scanning the Notre Dame Cathedral in 2001. It took him 4 years, scanned more than 50 locations for total 1 billion points of the whole building. Also, the game named Assassin's Creed Unity features an exquisite 3D map of the inside of Notre Dame cathedral based on the needs of the game scene. All these 3D datasets might help rebuilding Notre Dame cathedral in the future. In recent years, due to this kinds of archaeological sites might suffer from on-going wars, natural disasters, climate changes and human-caused destruction, the issues of heritage preservation have aroused people's attention. Needless to say, it's important to protect our tangible and intangible heritage and it's our duty to pass down to future generations. With advantage of accurate measurement results acquisition without destroying historical sites, using non-invasive optical sensors has become the main trend of recording archaeological documents method. These instruments have received much attention in recent years, also from non-experts for 3D surveying and modeling purposes. Generally, non-invasive optical recording sensors can divided into passive and active systems (Fabio Remondino, 2011). Passive sensors (e.g., digital cameras) collect image data which are then processed with some mathematical formulations to infer 3D information from the 2D image measurements. Normally at least two images are required and 3D data can be derived using perspective or projective geometry formulations. Active sensors (e.g., laser scanner or radar) can provide data directly from 3D information or ranges. Optical range sensors can divide into these species: pulsed(Time-of-flight), phase-shift, triangulation-based, interferometry-based and so on. In our case, we used a time-of-flight waveform recording scanner to obtain LiDAR point cloud data and used it to check the accuracy of image-based point cloud data of terrestrial images from handheld camera and aerial images from UAV.

Study Area

Madou old port (Fig 1) located in Tainan, Taiwan. It's an ancient port with at least 300 years history. Legends say that here was a dragons lair and the birthplace of the Emperor. Locals believed that it's a getaway paradise. It was an important port during Qing dynasty, responsible for exporting sugar and deer leather. It used to be prosperous area but because of siltation and the changes of the river channel, the port was no longer used. Taiwan government began archaeological excavation in 2003 and designated as level three ancient monument. Through time passed by, the wall of the port seemed to have a tendency to shift probably due to natural disasters or human-caused destruction.

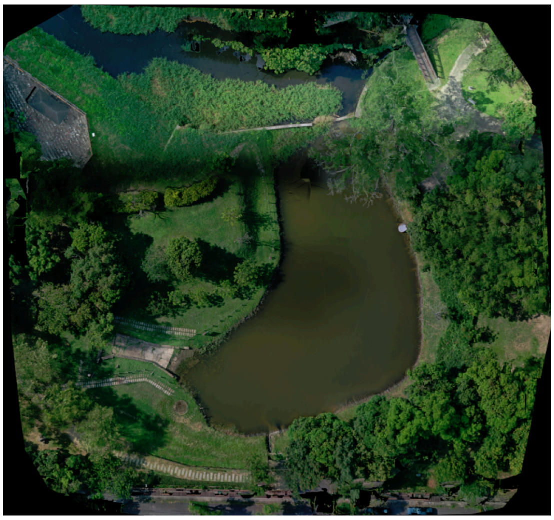

Figure 1. Orthoimage Of Madou Old Port Cultural Park

METHODOLOGY

Applied Optical Sensor

Terrestrial laser scanner (TLS) has been used for recording archaeological sites in recent years. It can scan large area quickly and reach highly accurate and reliable results at the same time. The TLS used for this work was RIEGL VZ-400 laser scanner, with a range accuracy of ±5 mm and repeatability of ±3 mm. In this survey, we set for total 13 scan stations to achieve complete point cloud data of out study area. In Figure 2, the position of each scan stations (yellow triangle icon) is presented.

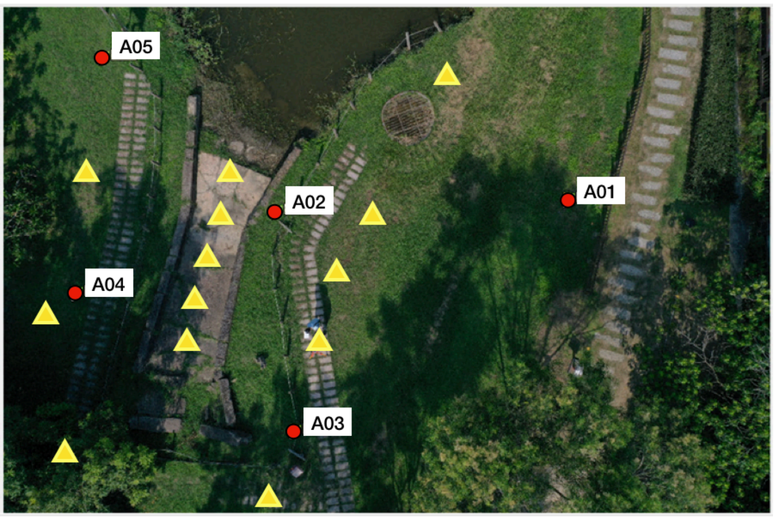

Figure 2. Location Of Each Scan Station (Yellow Triangle Icon) And GCPs (Red Circle Icon)

Unmanned aerial vehicles (UAVs) have advantage of precise navigation , control system and light weight sensors which can gain high resolution data and reach inaccessible locations easily(Abdullah et al., 2017). The UAV platform chosen was DJI Mavic 2 Pro. It's the latest product of DJI Mavic series. The specification of the UAV is mentioned in Table 1.

Table 1. Specification Of MAVIC 2 PRO

MAVIC 2 PRO	
Weight	907 g
Navigation	GNSS (GPS+GLONASS)
Max Flight Height	6 km
Max Fight Time	Approx. 25 minutes
Hovering Accuracy	Vertical: ±0.1m (when vision positioning is active) ±0.5m (with GPS positioning) Horizontal: ±0.3m (when vision positioning is active) ±1.5m (with GPS positioning)
Battery Capacity	3850 mAh

The UAV is mounted with a RGB sensor Hasselblad L1D-20c camera to acquire aerial image data of survey field. The handheld camera used for aqusition of terrestrial image data is Sony α5100. The related camera parameters listed in Table 2.

Table 2. Camera Parameters Of The Two Applied Camera

	Hasselblad l1d-20c	Sony α5100
Sensor	20 M pixel	24 M pixel
Focal length (mm)	10.3	16
Pixel size (mm)	0.0023	0.0039
Resolution (pixels)	5472 x 3648	6000 x 400
Sensor size (mm)	12.825 x 8.550	23.5 x 15.6
Navigation	GNSS	X

Field Work And Data Collections

A. GCP measurement

After conducting a rough field survey to check suitable placement of GCPs. We used plastic boundary monuments stuck with a CD with black and white pattern on it (Fig 3) as GCP mark. We total placed 5 GCPs around Madou old port and measured with e-GPS system.

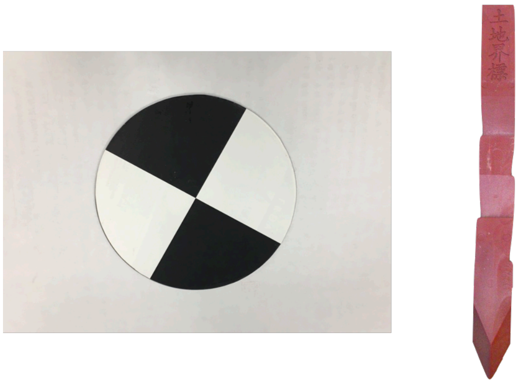

Figure 3. GCP Mark (Left) And Plastic Boundary Monument (Right)

B. Image data acquisition

For high resolution terrestrial imagery aspect, applying 16mm fixed focus lens and capturing the whole structure of Madou old port. The length of the old port is about 6 m and the width is 15 m. We took for total 1317 terrestrial images and after quality check, 1303 images were used for data processing.

For aerial imagery aspect, DJI Mavic 2 Pro's mission control software was used to formulate flight plan. Table 1 presented the information of the plan we set. The flight route (Fig 4) covered the whole Madou old port cultural park and extra shooting more imagery of the port. 336 aerial images was taken and used for data processing.

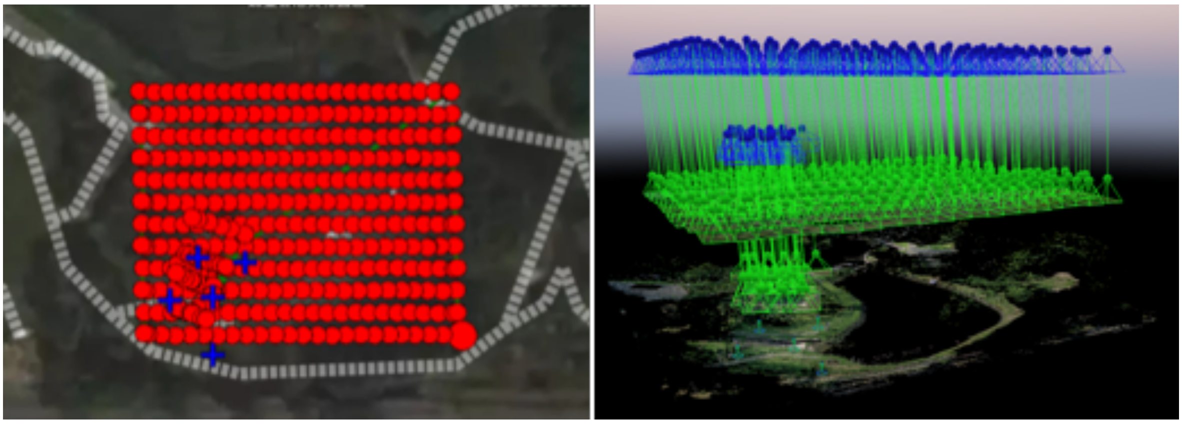

Figure 4. Flight Route In 2D Plane (Left) And 3D Space (Right)

C. LiDAR scanning

RIEGL VZ-400 was used to conduct LiDAR point cloud scanning. Scan angle range is from 30 to 130 degree and 0.04 degree of scan density. The position of scan stations was set to surround the port.

Data Processing

Agisoft Metashape and Bently ContextCapture software were used for terrestrial and aerial image data processing, RiSCAN PRO software was used for LiDAR point cloud registration and alignment. Most of photogrammetric software is using structure from motion (SfM) and dense stereo-matching algorithms to extraction 3D data from ordinary 2D images (Abdullah et al., 2017). 3D mesh model would be transformed from the dense point cloud generated from images. Although processing steps and used algorithms might be different, the principle is basically the same. The whole processing 3D mesh model steps in Metashape are as following: alignment of photo, camera calibration, generation of dense cloud, 3D mesh production, building texture. In Metashape, users need to click these functions step by step and it's a little bit tedious and time consuming. In ContextCapture, there're only two steps for building 3D mesh model: aerialtriangulation and reconstruction. All reconstruction procedure will be conducted after finishing aerialtriangulation. Reconstruction step includes generation of dense cloud, 3D mesh production, orthophoto/DSM, etc. Users no need to wait for each step's done to work on next step. Compare to Metashape, ContextCapture saves more time and convenient to users.For terrestrial image data processing, Metashape was used to generate dense cloud, 3D mesh and orthoimage. ContextCapture was used to process aerial image data. Ground control points are added through manual selection. On account of photography range, only 3 GCPs (A02, A03, A04) are used in terrestrial image data processing. RiSCAN PRO is the software developed from RIEGL company. It's used to register and align point clouds form each station. After multi-station adjustment, the deviation of multi-station registration is 0.0035 m. The result point cloud is exported for the following analysis after manually removing redundant points.

RESULTS AND ANALYSES

Open source free software CloudCompare was used to conduct the accuracy assessment. Since the output results data have real scale and coordinate system due to GCPs constraint. No need to register or align again, the function "Cloud-to-Cloud distance" (C2C) and "Cloud-mesh distance" (C2M) were chosen to conduct accuracy assessment and surface change detection. C2C and C2M function find the closest point/triangulate mesh between the two datasets and calculates their (Euclidean) distance then displays the resulting distances in color scale. In our case, the LiDAR point cloud are selected as reference cloud. The value of distance is smaller, the compared data would be more accurate. Furthermore, using the similar function can also compute surface displacement and the results have been proved to have high accuracy (Dimitri et al., 2013; Nicola Lercari, 2019). We have conducted survey on 31st May and 24th July and find out that there's no big change within two month. Yet for detecting surface displacement section would not be included in this study, it will be conducted in future works.

The Results of The Dense Point Clouds

Table 3 presented the numbers of each dense cloud from different data resources. The dense cloud from terrestrial image has the most dense data of all, almost 6 times more points than from aerial images.

Table 3. Point Number Of Each Dense Cloud

Data resource	Numbers of points
LiDAR scanner	19,090,718
Terrestrial images	60,816,474
Aerial images	10,717,156

After computation, the average distance between terrestrial-image-based dense cloud and LiDAR cloud is 0.05 cm, the deviation is 0.8 cm. Figure 5 present more explicit graph of statistic results. About 95% of point cloud distance is less than 1 cm. After checking, finds out that the places with larger value are due to weeds and stagnant water.

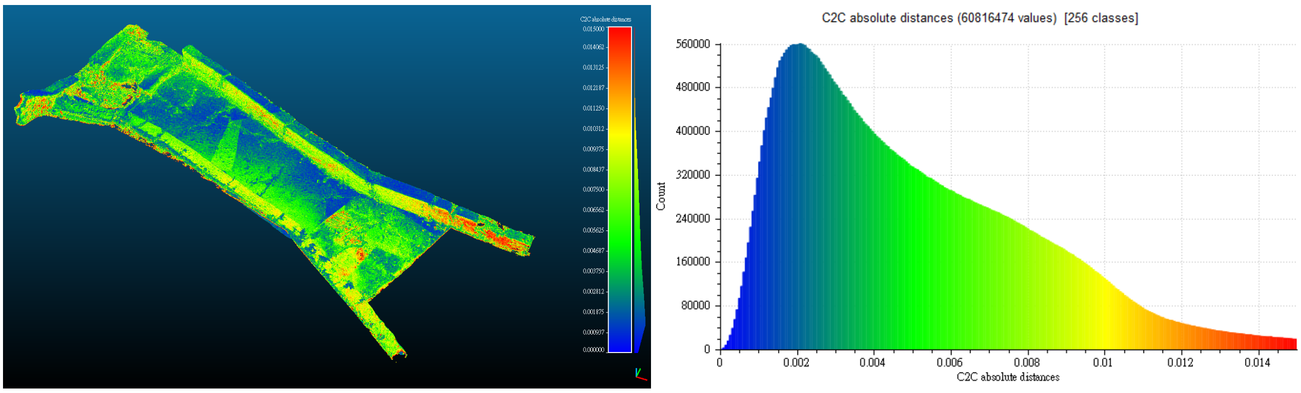

Figure 5. The Cloud Distance Result Between Terrestrial-Image-Based Dense Cloud And Lidar Cloud

Figure 6 shows the result of aerial-image-based dense cloud and LiDAR cloud. The average distance is about 0.07 cm and the deviation is 0.9 cm. 95% of point cloud distance is less than 1.5 cm. The places with larger value also occurred when there are weeds and stagnant water.

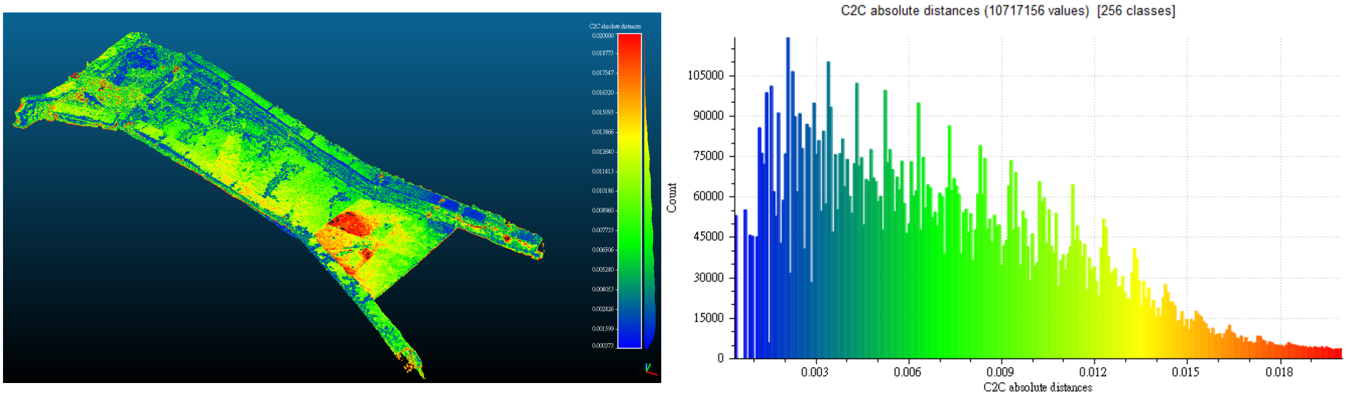

Figure 6. The Cloud Distance Result Between Aerial-Image-Based Dense Cloud And Lidar Cloud

The Results of The 3D Mesh Models

Table 4 presented numbers of triangulate mesh of the two models. Triangle numbers have significant between the two, the terrestrial-image-based mesh has almost more than 10 times number than the other.

Table 4. Triangle Number Of Each Mesh Model

Data resource	triangles
Terrestrial images	2,027,694
Aerial images	164,875

The average distance between terrestrial-image-based mesh model and LiDAR cloud is 0.7 cm, the deviation is 3.6 cm (Fig 7). About 90% cloud distance is between ±1.5cm.

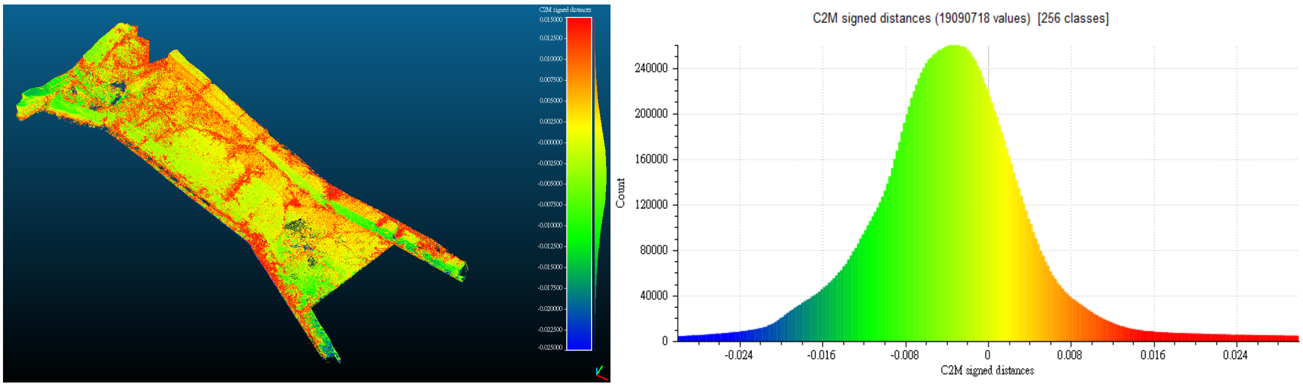

Figure 7. The Cloud Distance Result Between Terrestrial-Image-Based Mesh Model And Lidar Cloud

The average distance between aerial-image-based mesh model and LiDAR cloud is 0.9 cm, the deviation is 3.8 cm (Fig 8). About 92% cloud distance is between ±3cm.

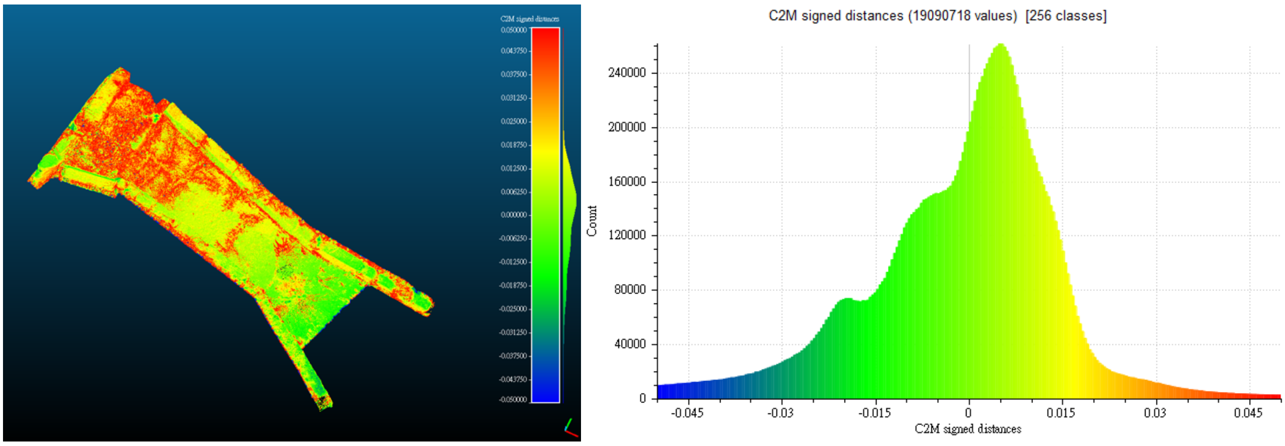

Figure 8. The Cloud Distance Result Between Aerial-Image-Based Mesh Model And Lidar Cloud

Accuracy Assessment And Comparison

Table 5. Quality Report

	Aerial-Image-Based Mesh	Terrestrial-Image-Based Mesh
Image Number	336 (46 images for only the port structure)	1303
GSD	5.7 mm/pixel	0.3 mm/pixel
Mean RMS error of GCPs	0.3 cm	0.4 cm

Table 5 presented the quality report of the two mesh. Although the used image and point numbers are very different, there's no significant difference in dense cloud comparison. Both statistic parameters are really closed. But in mesh comparison, the result of terrestrial-image-based mesh has is better than the other. Most of the distances are less than 1.5 cm, compared to the other, the value is 2 times smaller than the aerial-image-based mesh. In quality report, both 3D meshes are millimeter level precision models but the GSD values also have big difference between 2 mesh models. Overall, all results data have very high precision. Between dense cloud and mesh comparison, needless to say that the value of the dense cloud comparison is way better than the mesh even though both values are quiet small. Consider to detect deformation, using dense cloud datasets are suggested instead of the meshes.

CONCLUSIONS AND FUTURE WORKS

The quality of image-based mesh model is highly depend on images' resolution, numbers, object's material, complexity of the object, photography angle ,illumination, weather condition, etc. In our case, water sediment and weeds are the biggest obstacle during reconstructing models. It's hard to generate tie points due to their homogeneity. Also, blurry images due to human-caused vibration needed to be removed before import to photogrammetric software or will impact model's production, aerial triangulation, even value of the camera's calibration parameters. For measuring displacement of the target precisely, dense point clouds are suggested to be used instead of 3D mesh models. Reconstruction procedure in photogrammetric software might cause lacking fidelity (e.g. missing data or misplaced point). Even with highly accurate mesh model, the deformation results won't be precise. Though 3D mesh is a better way for digital conservation since its quantity of data has been simplified and if not conducting any precision measurement, mesh model is enough for basic survey. Also, due to measuring error and accuracy of the produced results, how much changes are considered to be displacement is needed to be decide.

In the future, we'll do the whole process again after six months and compare these two different time periods data results to observe the deformation of the port's wall. Try to remove vegetation and find out other more suitable and precise way to value and present the state of the deformation. Provide the final results to government for conducting the following-up conservation plan of Madou old port.

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