DIGITAL HERITAGE AND PRESERVATION: AERIAL PHOTOGRAMMETRY AND LIDAR APPLIED TO THE MAPPING OF KAPAYUWANAN, INDIGENOUS PAIWAN SETTLEMENTS, TAIWAN

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KEY WORDS: digital preservation, cultural heritage, archaeology, indigenous settlements, UAV photogrammetry, LIDAR, Mapping, Kapayuwanan, Paiwan, stone slab houses

ABSTRACT:

This paper discusses the application of UAV and Terrestrial photogrammetry and LiDAR for mapping Taiwanese indigenous Settlements. The relics of Taiwanese indigenous settlements with thousands history are widely distributed in deep forestry mountains with inconvenient transportation. Kapayuwanan is the original place of paiwan indigenous people. Firstly, UAV photogrammetry is applied for mapping supayuan settlement of 8 hectares and those stone houses invisible under dense forest are drawn by in-site investigation. Then UAV photogrammetry and LiDAR are used to document the larger area of Kapayuwanan of 36 hectares and terrestrial Lidar for the area of 1.2 hectares sorted out. It can not only obtain the accurate topography, landscape with architecture but also reveal the hidden settlements, such as roads, stone slab houses, irrigation landscape under the dense forest. Accuracy mapping is fundamental for future preservation planning and virtual conservation.
Shaping the future is from revealing the Past. That is crucial to document, understand, and preserve the precious cultural heritage. Documenting with immediacy, high resolution, high manoeuvrability become possible because of the rapid developments of digital technologies in the recent two decades. It’s astonishing, in the case of Taiwanese indigenous archaeological settlements sites, UAV photogrammetry and Lidar can successfully reveal the relics of stone slab houses in such a sever site – steep slopes, dense forestry with plantation in biodiversity. The reveal of settlements with reclaimed landscape verifies oral transmission of indigenous people as well . Digital technologies support the contention of archaeology, anthropology, heritage preservation, and cultural landscape, indispensable for revealing the past and shaping the future.

1. INTRODUCTION

Arial and terrestrial photogrammetry and Lidar have rapidly developed in archaeology and documenting cultural heritage in the past two decades (Heckenberger et all, 2003; Crutchley, S.P., 2010; Doneus and Briese, 2010; Prumers et all, 2022). Especially, aerial LiDAR technology, proven to be particularly useful in areas of extensive upland to reveal the unseen settlements under the dense forestry brings lights to the survey of Taiwanese indigenous settlements. In Taiwan, the development of applying laser scanning started in 2005, firstly used in the scanning a temple needed to be urgently rescued (Lu, 2008) and two decades later, this is also the first time to use airborne photogrammetry and LiDAR to proceed in such steeped and extensive sites to reveal the hidden man-mad structure under dense forestry.

The relics of Taiwanese aboriginal settlements with thousands history are widely distributed in the deep forestry mountains with inconvenient transportation. Kapayuwanan, between altitude of 620~990meters, at the top area of Dawu mountains, southern part of Taiwan, is the original place of indigenous people according to paiwanese oral transmission (Figure 1~3).

Several settlements are distributed in the area of Kapayuwanan most of which are covered with dense forest nowadays in the area of circa 400 hectares. The archaeological evidence of radiocarbon dates is around 2200B.P. at nearby maslid settlement (Liu, 1991). The investigation of old Paiwan settlements started in 1999, and the research was firstly published in 2003 (Lu and Kao, 2003)

With the help of aerial photogrammetry and LiDAR, it has amazingly revealed the hidden settlements which are verified by the oral transmission of indigenous people. The airborne LiDAR is able to penetrate the dense forest and obtain the reclaimed landscape information including man-made structure, such as stone slab houses, roads, interrupted (cultivated) patched land, and irrigated terraced field in the steep slope. It shows the vast population density at least since15th century inferred via ancestry which is completely different from the current status (Utsurikawa, 1935; Lu, 2022). Therefore, we can have more physical evidence to interpretate site selection, settlement changing process, transformation of landscape, and the anthropogenic impact on environment of Paiwan indigenous settlements over the past two millennium. The integration study of architectural anthropology, landscape ecology, archaeology, cultural heritage, and with 3D digital technology has the significance for the various issues on heritage preservation and especially in the study of the indigenous settlements.

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Figure 1. the location of site

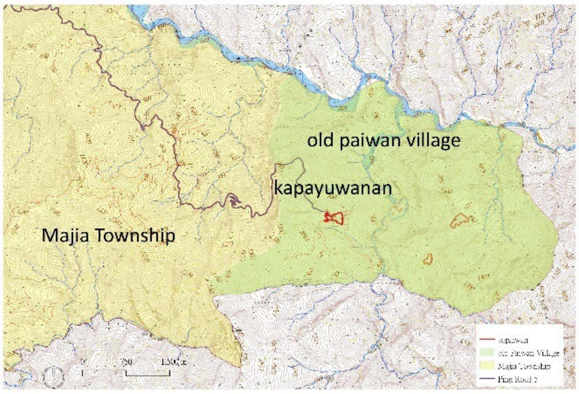

Figure 2. Kapayuwanwan in Majia Township, Taiwan

Figure 3. Kapayuwanan (680m), the place which has cooking smoke, facing the Dawu mountain (3092m) its upper part is supayuan (860m), across the Itapu river is the settlements of padain (980m). There are at least 12 settlements under the dense area. Indigenous paiwan people earnestly would like to rehabilitate the lost settlements of their ancestors’ home, their original place to come from.

2. AERIAL PHOTOGRAMMETRY

2.1 Flight Plan

UAV maneuvering performance goes deep into the aerial photography area to complete data collection. In addition to basic photo shooting, flight rote is also carefully planned to proceed aerial photogrammetry. In addition to achieving the purpose of the flight, it is also necessary to pay attention to the protection of operators, surveyors, and the general public and to consider the emergency response in the event of an accident. The UAV lidar scanning and aerial photography used in this plan require a flight plan before the flight mission can be carried out. A complete flight plan should include terrain survey, ground control point (GCP) planning, GPS positioning measurement of control points, take-off and landing point assessment, route planning, and flight personnel allocation, traffic control, and other parts. The overall operation should be adjusted according to the environment after completing the preliminary planning indoors. The survey area is about 8 hectares (680m~860), and the route planning is shown in Figure 4 and Figure5. In order to improve the shooting effect of lateral buildings, in addition to the frontal shot, a 45-degree side shot is added. The side overlap rate used is 85% and the heading overlap rate is 80% for the frontal shot. The side overlap rate used is 60%, and the heading overlap rate is 70% for the side shot. The operation process of overall flight plan is shown in Figure 6.

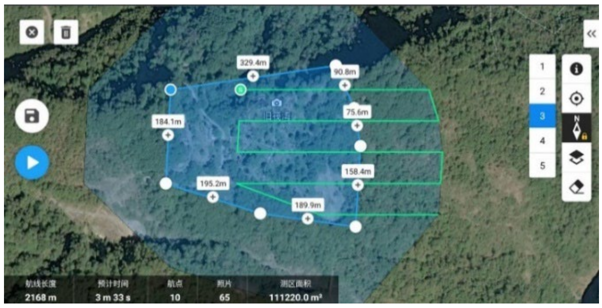

Figure 4. Flight route planning (1) - side shot

Figure 5. Flight route planning (2) - frontal shot

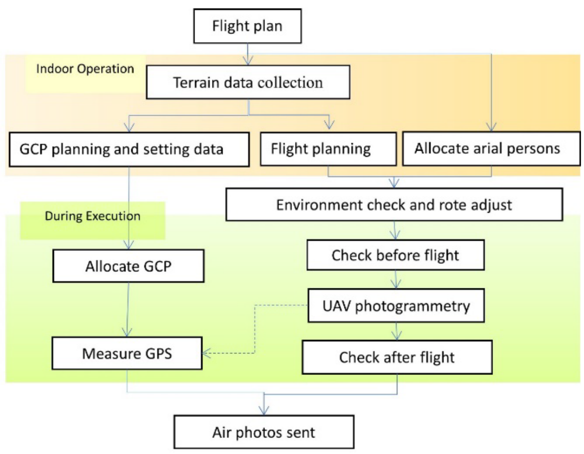

Figure 6. Flight rote process

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2.2 UAV (Unmanned Arial Vehicle)Aerial Photogrammetry and Orthophoto Data Construction

The development of the UAV platform requires a variety of technologies, including platform development, data post-processing, and image analysis (Kelcey and Lucieer , 2012 **)** This project uses the principles of aerial triangulation (Aerotriangulation) which means that using the spatial geometric relationship between the aerial image and the shooting target, the plane position, elevation of the point, and the external orientation elements of the photo are calculated according to the feature of the photo in the measurement proces. In order to increase the completeness of subsequent image processing, the overlap rate between the captured images must provide sufficient point cloud feature points. On the same route, the aerial photos must overlap each other by more than 75% (course overlap rate, overlap), and the aerial photos between the two routes must overlap each other by more than 70% (lateral overlap rate, sidelap)

The post-production of aerial photos requires SfM (Structure from Motion), 3D reconstruction cloud computing technology, which is applied to obtain ultra-high-resolution 3D models from multi-view aerial photography (Lucieer, de Jong, and Turner, 2014 **)**. Arial images can produce point clouds by means of Multi View Stereopsis techniques (MVS) (Harwin and Lucieer, 2012). The purpose of 3D reconstruction is to establish a method for 3D objects to be represented and processed by a computer. The main method is to use 2D images to restore their 3D information through mathematical calculations. This is a cloud computing technology that combines SIFT (Scale Invariant Feature Transform) and SfM. SfM is to determine the spatial and geometric relationship of the target through the movement of the camera, and it is a common method for 3D reconstruction. It only needs a common RGB camera lens, and the technology can be used both indoors and outdoors. It is applied to make DSM (Digital Surface Model) from the aerial images of UAV. SIFT can extract image feature points and perform vectorized description of the feature points, then match the feature points with vector description, and remove the feature points that match incorrectly, and use the correctly matched feature points to perform image stitching. Adjust the geometric differences between the images, complete the image stitching work, and perform operations on the extracted point cloud data through the Kriging method. Not only can the captured images be quickly mosaicked, but also the 3D point cloud data on the surface can be converted into DTM (digital terrain model) (Wang and Huang, 2014 **)**. UAVs have the characteristics of immediacy, high resolution, and high maneuverability. With aerial triangulation technology, the captured images can be reconstructed into three-dimensional models, DEM (Digital Elevation Model), DTM (Digital Terrain Model), DSM (Digital Surface Model), and orthophoto, if the ground control point (GCP) setting is added, the terrain error can be controlled within ±5 cm.

2.3 Aerial Survey Results

Aerial photogrammetry was carried out on 2022/06/04. With full-frame camera RXIRII, 1.5 cm resolution orthophoto of aerial photography can be obtained at a shooting height of 120 meters, and can be combined with PPK (Post Processed Kinematic) system and ground control points (GCP) to be improved to 10 cm shooting accuracy.

Overlaying maps between digital surface model, sunshade, and elevation rendering, and orthophotograph generated from aerial photogrammetry with cadastral map are shown in Figure 7~8.

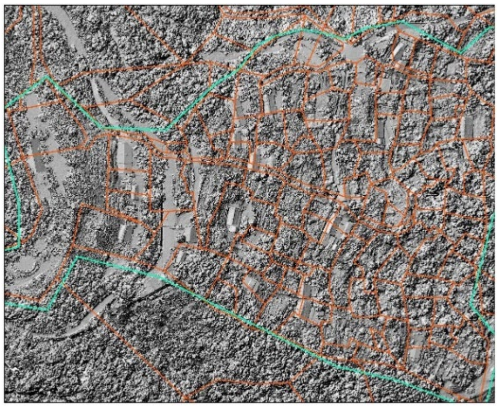

Figure 7. Digital surface model of sunshade overlays cadastral map of Supayuan

Figure 8. Orthophotograph overlays sunshade and cadastral map of Supayuan

2.4 Process of Making Maps for Planning

The process of building map data: Firstly, make a topographic survey base map from the GIS map data platform, and then draw a preliminary planning base map. On-site investigation draft was drawn (Figure 9) and later to be digitized (including revising the existing information), and finally aerial survey (UAV shooting/3D scanning) is performed to inspect the existing conditions and overlay image and digital graphics. One previous air photos from UAV as shown(Figure 10).
That is, the orthophoto map (Figure 11) is embedded under the CAD software system, the in-situ survey data is checked and digitized, and the accurate Supaiwan settlement site plan and conservation planning master plan can be drawn in CAD (Figure 12). Afterwards, the 3D visual software can be used to view and check the longitude/latitude and elevation of each position in the settlement. The surface topographic profile is produced from aerial photogrammetry (Figure13) or through the existing GIS topographic and building maps, checking the elevation value to draw the topographic profile of the settlement. Besides, the 3D data of the aerial survey can be integrated into the 3D drawing software, such as Rhino, and the topographic profile can also be drawn directly. Furthermore, through the detailed in-situ survey, the authentic situation of settlement landscape and building profile can be adjusted and drawn (Figure 14). In addition, the southern-eastern block of the settlement is located in a dense forest area, and aerial photogrammetry cannot penetrate the woods to obtain the information of slate houses. Therefore, the slate houses under the dense forest are drawn only by detailed on-

site investigation. Subsequent use of airborne lidar (installing the scanner on the aircraft) assisted with ground 3D scanning when terrain allows, which may have a better effect on penetrating dense forests to obtain topography(Prumers et all, 2022). This part will be solved at the second arieal survey and terrestrial scanning in 2023.

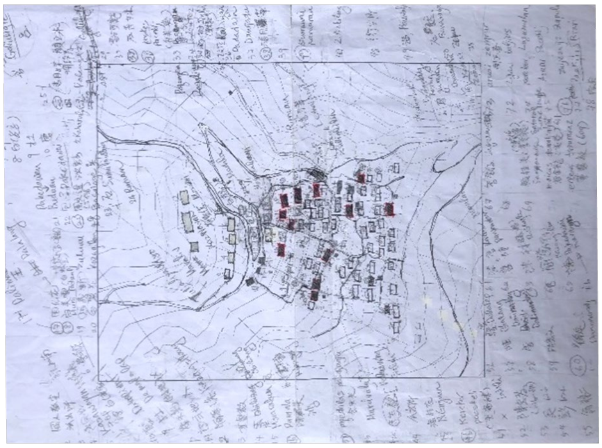

Figure 9. Conducting the survey of 100 stones houses with the survey base map of Supayuan (This is hand-drawn draft by April Hueimin Lu in 2022 before the southeastern corner of forestry area sorted out).

Figure 10. the air photo of UAV, by Susan Liu, 2021

Figure 11. Supayuan orthophoto image (11 hectares), 2022

Figure 12. Supayuan House Configuration and Settlement Preservation Plan, 2022

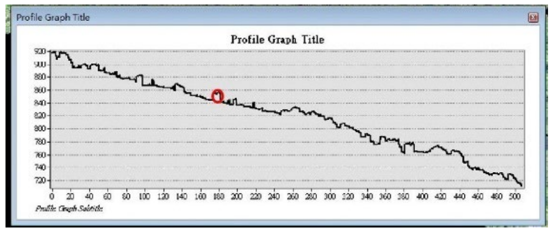

Figure 13 Topographic profile and elevation values of the settlement surface

Figure 14. Supayuan Settlement Landscape and Architecture (slate houses) Sections, drawn in 2022

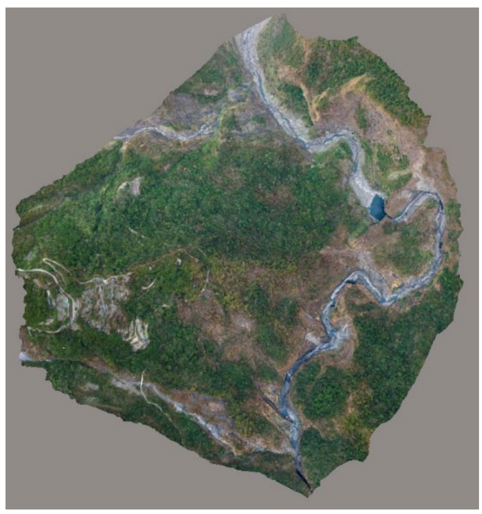

Figure 15. Kapayuwanan orthophoto image (400 hectares) , 2023

In 2023, the further survey of Kapayuanan (including Supayuan) was carried out - an arial photogrammetry of kapayuwanan, 400 hectares, a greater area than previous task of 11 hecaters in 2022 (Figure 15). And the airborne scanning of 40 hacaters are proceeded including supayuan. The western corner with dense forestry are sorted out by the time we carried out the second aerial survey with Lidar, so we carried out the terrestrial LiDAR in order to get fine scanning result with details(Figure 16). This time, we get better effect of the stone slab houses through 3D ground scanning of 2 hectares to get accurate layout of houses (Figures 17).

Figure 16. Image of 3D scanning of the relic, 2023

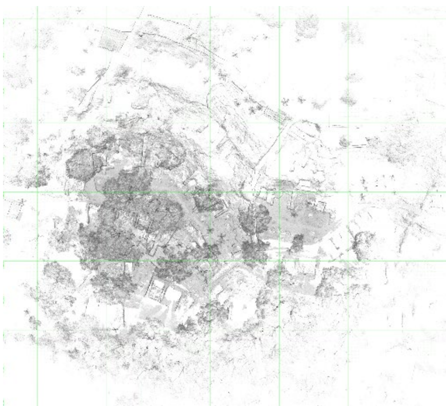

Figure 17. Layout of stone slab houses from the terrestrial LiDAR

3. THREE DIMENSIONAL DIGITAL SCANNING TECHNOLOGY - ARIAL AND TERRESTRIAL LIDAR

3.1 3D digital scanning technology applied to the survey of Kapayuanan

In 2023, the further survey of Kapayuwanan (including Supayuan) was carried out - an arial LiDAR of kapayuwanan (660 m ~860 m), 36 hectares, and ground 3D scanning of the main sorted out relic area (660m~680m), 1.2hectares.

The aboriginal settlement of Kapayuwanan with stone slab houses can be mainly distinguished into two areas according to the dense of the forestry : the known area , the relic being sorted out, and the unknown area being suspected to have houses from the memory of the elder. Known areas in the process of sorting out need fast, high-precision, and complete digitization to avoid damage to human activities in future development and use. Unknown areas need to be able to breakthrough dense forests, 800-meter high mountains, with no mountain roads, inaccessible, and large-scale difficulties (Figure 18~19) .

In order to effectively preserve the ruins of Kapayuwanan slate edifications and their current appearance, a ground 3D scanner (Terrain Scanner, Z+F 5016 imager) was used to completely preserve the status quo of the existing slate buildings of the ruin sorted out. The area is about 1.2 hectares with the altitude of 660~680m. Besides, in order to determine the scope of original aborigines' activities, a new technology that can judge the type of slate edifications in a large area is needed.

In addition to the high-precision camera of the unmanned aerial vehicle, the high-resolution aerial images are collected and the laser scanning technology (LIDAR, Light Detection And Ranging) draws high-precision and high-resolution digital point cloud terrain. This research uses airborne laser scanning records to collect trees, buildings, and surface (digital surface model, DSM) point cloud data, and judges the distribution area of buildings through post-processing analysis .The area is about 36 hectares with altitude of 680m~860m.

Figure 18. The area of aboriginal settlement of slate houses in the high mountain (the research area is at the overlap of a satellite imagery and an aerial photo)

Figure 19. Yellow area is the known area with relic sorted out, and the orange area is the investigating area with dense forestry and no accessibility.

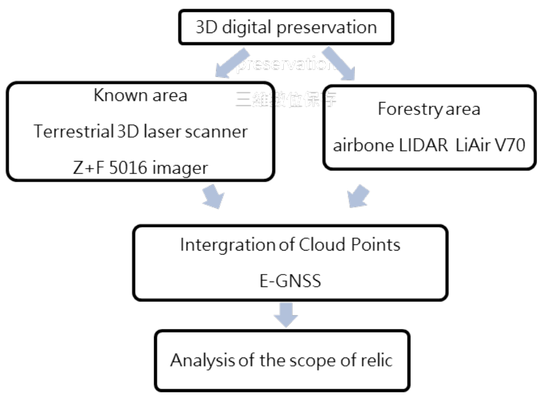

Figure 20. The process of 3D scanning

Plan to confirm the scope of ground scanning and UAV flight survey, set 4 common ground control points and 5 aerial photography ground control points, and use high-precision GPS equipment to achieve measurement accuracy within 2 cm in the E-GNSS method. The known finishing area adopts Terrestrial 3D laser scanner Z+F IMAGER 5016, the best precision at 200 meters (m) is 1.7 millimeters (mm), and the average point distance is about 7 millimeters (mm). Detailed digital recording is done in a panoramic way (360° x 320°), including a point cloud with a radius of 360 meters and a HDR camera with a high dynamic range to generate a 400 million pixel panoramic image (Figure 20) .

Record and organize the real scene colour 3D point cloud model of the slate ruins in the dense forest area, accurately record the distribution position of the slate houses, the landscape, and the surrounding terrain to verify the legends and historical materials passed down by the elders and restore aboriginal settlements (Figure 21~25).

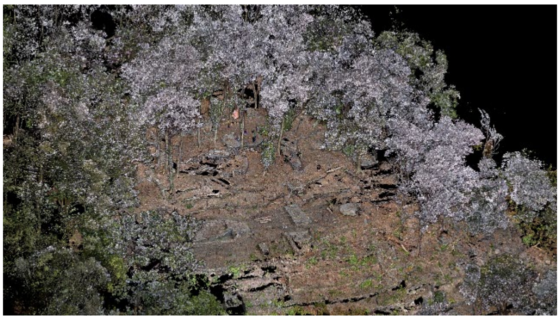

Figure 20. Confirm the scope of the ruin area sorted out, Constructed edification existed in the dense forestry

Figure 22. High-precision digitalization of stone edfication of the relic sorted out, Stone construction distrubuted according the terrain

Figure 23. Point cloud presentation without tree data

Figure 24. The colorful mode of real scene of cultivated land of the relic

Figure 25. The colourful model of real scene of the relic

The aerial multi-echo LIDAR (GreenValley LiAir V70) is used in dense forests and high mountains, with an optimal scanning distance of 80 meters, an accuracy of 2-5 centimeters (cm), and a 24-megapixel camera.

The flight height of the whole area is controlled to be 60-100 meters above the ground. The laser light reflects the characteristic signals of different ground objects with multiple echo signals to collect the surface data of the area with a length and width of about 370 meters and a forest height of about 25 meters. The scanning point cloud density is about 1400 point/m2, and the accuracy of the common ground control point is about 8.69mm when the empty point cloud overlaps the ground scanning point cloud. The point cloud data can be mutually verified to confirm that the scanned data is correct, and then judge the distribution area of slate houses.(Fig. 26)

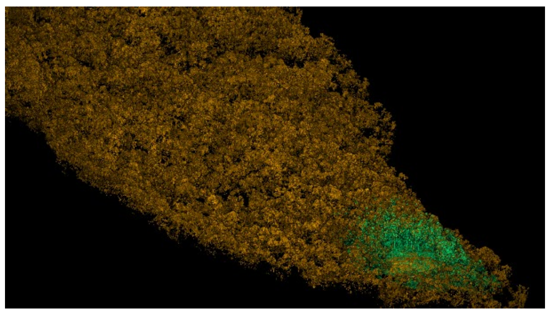

Figure 26. Overlap of lidar and ground points cloud data, Average ICP error: 0.0869 m, Maximum ICP error allowed:0.0874m

The data is about 8% of the point cloud at the lowest height to establish a mesh (mesh), and the surface characteristics are directly used to analyze and judge the distribution of the stone slab ruins. After the mesh is established, adjust the transparency of the three-dimensional terrain mesh to strengthen the surface features to produce a clear contrast, which is easy to judge and analyze mountain roads and different terrain areas. After the

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mesh is established, adjust the transparency of the three-dimensional terrain mesh to strengthen the surface features to produce a clear contrast, which is easy to judge and analyze mountain roads and different terrain areas. For example, the light blue area is the known stone slab ruins area, and the purple area is judged to have been reclaimed according to the terrain. The terrain is like a contour line and there are long strips of stone slab structures facing away from the mountain. The yellow terrain has obvious characteristics of reclaimed farmland. (Figure 27~34)

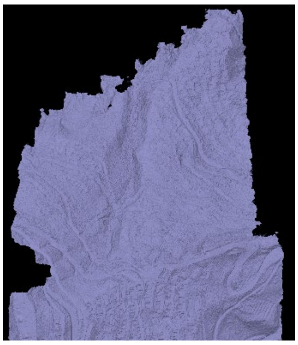

Figure 27. Orthophotograph from point cloud of Kapayuwanan
Figure 28. Mesh of point cloud of the lowest height from Arial LIDAR

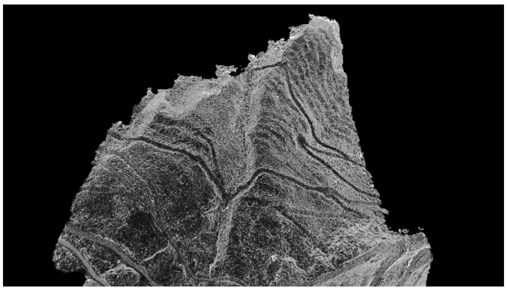

Figure 29. Check the characteristics of terrain by adjusting transparency of mesh

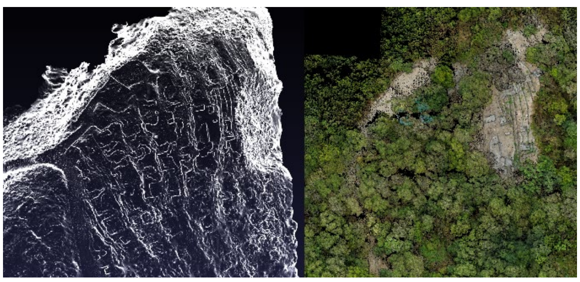

Figure 30. Comparison of mesh in transparency and orthophotograph from point cloud in detail of the surrounding of the known area

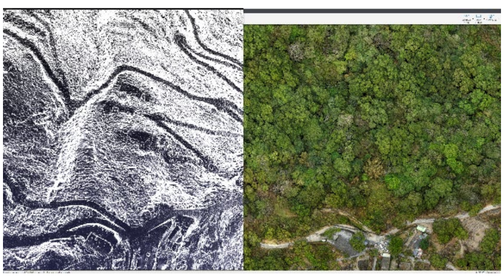

Figure 31. photograph from point cloud, especially the stone slab houses being sorted out and roads are clear even under the dense forestry.

Figure 32. Overlap of mesh in transparency and orthophotograph

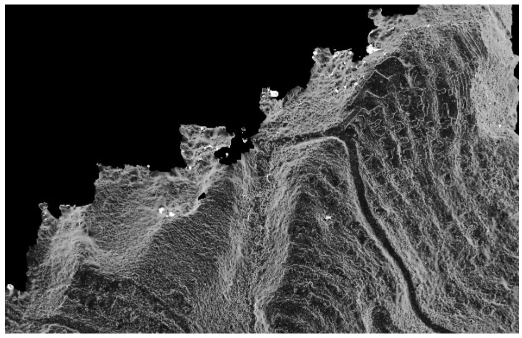

Figure 33. Judge the road and reclaimed landscape

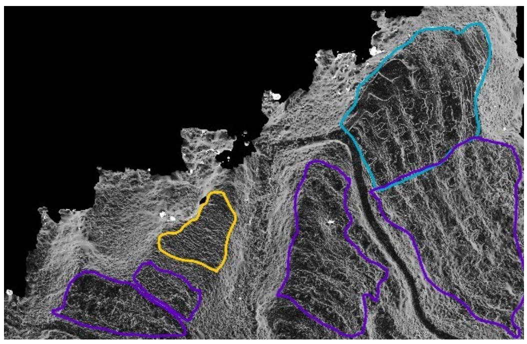

Figure 34. Different characteristic demonstrate various land use patterns –extensive occupation by man as for the understanding of anthropogenic impacts on environment.

4. CONCLUSION

The special characteristics of Taiwanese indigenous settlements widely distributed in the high forestry mountain, just very much suitable for airborne LiDAR to detect the possible existence of settlements. This is the first time to proceed the combinations of arial photogrammetry, airborne and terrestrial LiDAR in Taiwanese indigenous settlements in Taiwan. Kapayuanan about 400 hectares with altitudes of 350~860 meters, a large-scale of three-dimensional spatial information are collected.

Aerial photogrammetry is immediate and accurate. For the topography under the dense forest, airborne LIDAR and ground station LiDAR is used which can quickly, accurately, and meticulously collect the detail information of architecture. Finally, the point cloud data are integrated and a complete 3D model of the site is presented. The orthophoto map obtained by aerial photogrammetry and the data of on-site investigation are integrated into the CAD drawing software platform to quickly and accurately draw the layout and site section map. Therefore, the results of this study show that in large-scale settlement surveys, aerial survey technology can be efficiently used in mapping. The 3D scanning makes fine records of individual buildings, which greatly increases the efficiency and accuracy of surveying and mapping work. It provides the accuracy data for the restoration of the settlement and landscape. Finally, the essential contribution of this paper is to apply arial LiDAR and mesh of the lowest height of point cloud, the artificial structure can been, and through manipulating transparency of mesh, one can even more clarify the artificial structure even in the dense forestry, it will very much helpful for understanding and detecting the existing cultural heritage and for conservation as well for those inaccessible sites in the dense forestry, the situation of most of Taiwanese aboriginal settlements. Although the discovery of the hidden relics under forestry in the upper Xingu region of Brzil in the natural forest Amazon and the techniques have been developed rapidly in recent 20years, the results of the project in Kapayuwanan in Dawu mountain of southern Taiwan is fruitful and at some points, is astonishing. Its accomplishments can compete the contemporary researches in 3D digital technology in the field of heritage preservation. Firstly, the site is extremely difficult, steep slope and complicated plantation with 3 layers in terms of high biodiversity, much denser than Amazon. The steep slope, high density of forest, and complexity of plantation and topography make the mission impossible, which the 3D-digital technicians have no hope to conquer, and also it has not been worked out in the world. One of the key points turn out to be successful is the known area sorted out by an indigenous family in advance, it can have good reference to get the real surveyed topography and very much help to judge the man-mad structure on the ground. Of course, the leader of the team, prof. Lu, an architectural anthropologist, is very much familiar with this area and have the data from the oral transmission. Furthermore, the Lidar technicians have more than 20 years of experience, hence the flight plan is carefully planned and skilfully processing the data and the mature judgement. Owing to its high resolution and the skilfully manipulation the transparency like X-ray image of the landscape to get the astonishing discovery in details, it can detect the existence of remains as many as possible and the transformation of landscape which leaves a lot of information to diagnosis. Our result can been recognized as one of the leading researches as far as I know at present, the application of combinations of the aerial and terrestrial photogrammetry and LiDAR technology to the extreme in such efficient way. For those abundant information can have much better interpretations for the history of indigenous cultural and the resilient way of living , cultivated, and the sustainable management of natural resources can be better understood and passed down to us. That is the core value of cultural heritage preservation and that is also the most significant value to develop survey technology.

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