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Proceedings of the Sixth International Scientific Conference

EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE

GREEN
EME 2023

SCIENCE AND TECHNICS
PUBLISHING HOUSE

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SUSTAINABLE AND GREEN ENERGY TRANSITION CIRCULAR ECONOMY IN RESOURCE-MINERAL MANAGEMENT AND SUSTAINABLE DEVELOPMENT

(Wind power, solar power, gas power, geothermal, garbage power, hydrogen, etc.; low carbon emission technologies; resource-mineral management and sustainable development)

CLIMATE CHANGE AND DISASTER MITIGATIONINNOVATION MEASURES FOR EARTH, MINING AND ENVIRONMENTAL SCIENCES (innovative measures for earth, mining and environment sciences to meet sustainable development goals)

DEVELOPING A THREE-DIMENSIONAL MODEL OF THE OPEN PIT MINE AND THE INDUSTRIAL YARD OF NUI BEO COAL MINE

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Abstract: To achieve the goal of building a 3D model of the mine surface area which includes the open pit mine and the industrial yard of an underground coal mine (SCN), an unmanned aerial vehicle (UAV) was used to collect data for the establishment of 3D point cloud (PC) and orthomosaic image of this area, which is about 100 hectares and located at Nui Beo coal mine. The area includes an open pit mine with a depth of 110 m and SCN with a flat terrain, but there are many important works of the mine, especially a mineshaft tower with a height of 50m. To obtain a complete point cloud (PC) for 3D modeling purposes, the terrain characteristics of the area were studied, and three aerial photography scenarios were designed for each location, including: (1) capturing orthogonal images of the entire area, (2) capturing additional images of the industrial mining structures using a 45-degree oblique grid method, and (3) capturing circular path images at 45 and 60 degrees focusing on the well tower. Image processing for each of the above aerial capture scenarios resulted in incomplete and insufficient data for detailed model rendering. The PC was generated by combining images from the three supplementary methods to compensate for each other's deficiencies and provide a comprehensive overall point cloud. The accuracy of the PC was evaluated based on a root mean square error smaller than 3.0 cm, with the maximum deviation in ground position and height of the corresponding model points being 4.5 cm and 4.2 cm, respectively. Using the established PC, a 3D model of the combined area of open pit mining and SCN35 of the Nui Beo coal mine was constructed.

Key words: *Industrial area, Open pit mine, UAV, 3D model, Nui Beo coal mine.*

1. INTRODUCTION

According to Decision 403/QD-TTg regarding the coal industry development plan in Vietnam, by the year 2030, open pit coal mining will only account for 11% of the total production (Prime Minister, 2016) [1]. Mining operations are gradually shifting towards underground mining since coal seams are increasingly deeper, resulting in a higher stripping ratio, which reduces mining efficiency. During the initial construction phase of underground mines and the early operational phase, mines such as Nui Beo, Ha Long, and Ha Lam continue to operate both open pit and underground mining. During this stage, the management of open pit and underground mining operations takes place concurrently.

Creating three-dimensional models is an essential spatial database that significantly improves the efficiency of mining operations and resource management. [2]. Consequently, the establishment of 3D models for mines has been carried out in numerous research studies and practical applications. Integrating point cloud data obtained from Unmanned Aerial

Vehicle (UAV) imagery and Terrestrial Laser Scanning (TLS) data to create 3D models for open pit coal mines was conducted in the research by the author Le Van Canh [3]. In another study, Hao Zhao and colleagues developed a 3D model of an open pit coal mine, which showcased geological features such as cracks and faults on the mine's surface, emphasizing its significance as an essential information platform for mine design and management [4].

UAV technology allows for rapid data collection over a wide area [5]. The nearly featureless terrain of the mining area is advantageous for UAV applications [6]. However, the highly variable terrain of the open pit mine area requires accurate elevation data for mining volume calculations, and 3D modeling efforts focus on terrain features. Therefore, when designing UAV aerial photography for the open pit mine, careful planning of flight paths and positions is essential for both safety and accuracy [7]. In contrast to the open pit mine, the industrial mining site has relatively flat terrain with minimal elevation changes, and the influence of terrain features on elevation accuracy is negligible. However, when creating a 3D model of this area, terrain features become crucial and need to be thoroughly examined [3]. With the different characteristics of terrain features between the open pit mine and SCN, when applying UAV technology for 3D modeling of both areas, detailed studies on elevation differences in the open pit mine and the structure of industrial facilities on SCN are necessary. This involves calculating relevant parameters and developing suitable aerial photography methods for each specific area, ensuring both economic and technical considerations are met.

The terrain of open-pit mine differs from the existing structures on the industrial yard. Therefore, it is crucial to determine suitable UAV flight and image processing methods for both of these objects when establishing a 3D model for this combined area.

2. STUDY AREA

The research area covers 100 hectares within the Nui Beo coal mine in Ha Long, Quang Ninh (Figure 1). Within this area, the open pit coal mines zone occupies 12 hectares, while the rest is designated for highwall mining.

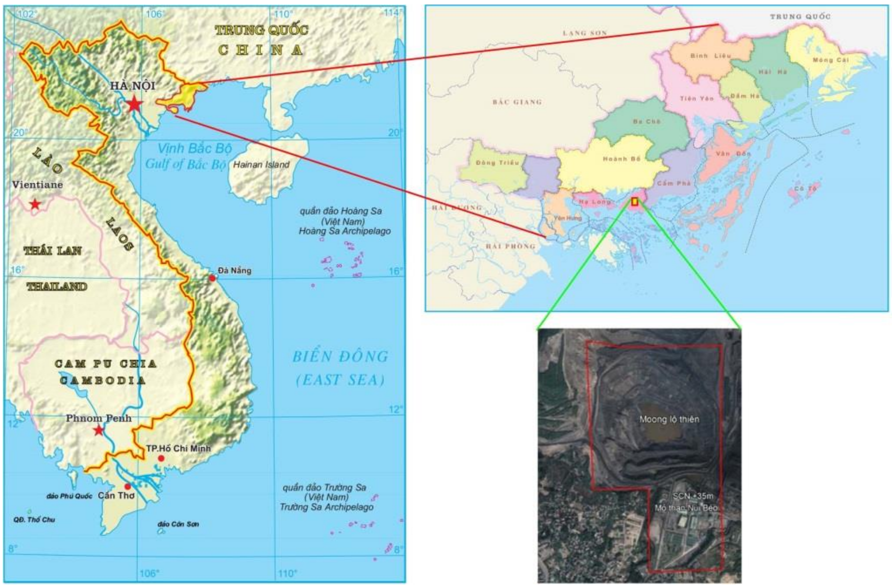

Figure 1. *Study area at Nui Beo Coal Mine, Ha Long, Quang Ninh*

The open pit mine's terrain has a height difference of 110m, ranging from an elevation of +25 meters to -85 meters. The terrain is characterized by terraces and slopes (Figure 2a). In practice, this area proves to be favorable for data collection using UAV (Unmanned Aerial Vehicles) because the terrain is virtually devoid of natural features (Figure 1).

The SCN35m area, on the other hand, has relatively flat terrain at an elevation level of +35 meters. However, this area is home to various industrial mining structures with different sizes, shapes, and structures (Figure 2b). Collecting data using UAV technology in this area requires research to ensure capturing images of the walls and bases of these structures, thereby ensuring the acquisition of complete point cloud data for the construction of a 3D model.

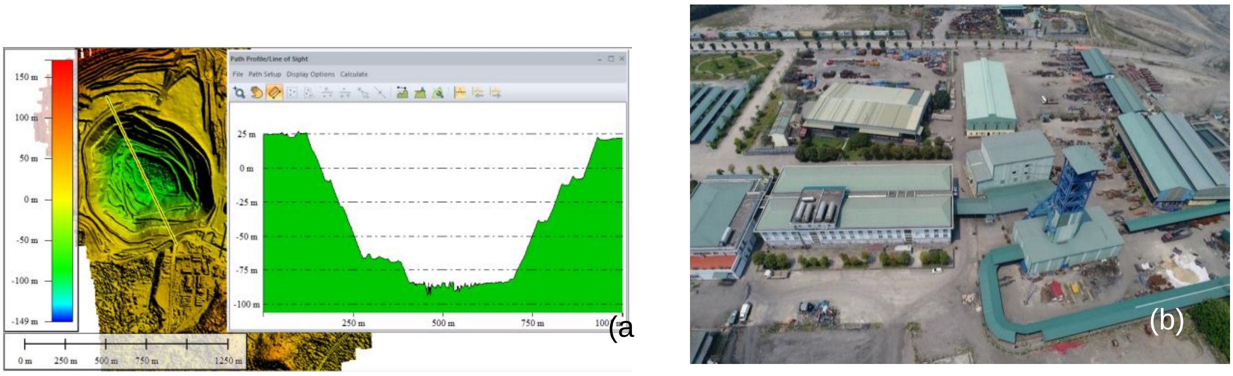

Figure 2. *Topographic features of the study area*

a) Cross-section of the terrain of the open-pit mine; b) Industrial building in SCN35 area

3. MEASUREMENT METHODS AND DATA COLLECTION

3.1. Ground control point determination

Image control points and check points are designed as shown in Figure 3a, consisting of points placed on the terrain surface and points affixed to the object's surface in the vertical direction. Ground points are marked using image control point targets designed as in Figure 3b. These points are evenly distributed throughout the research area, particularly in the lunar landing area, ensuring uniform placement in both position and elevation.

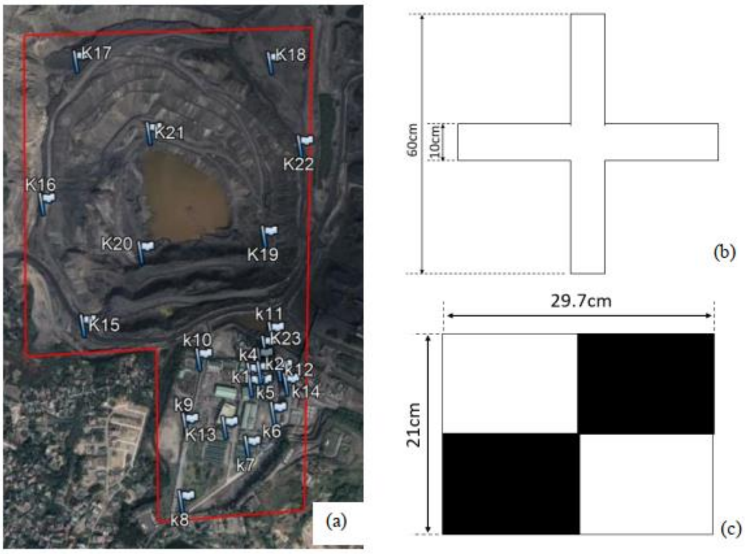

Figure. *3. Control Points and Checkpoints* *a) Designing GCPs on Google Earth; b) Ground Control Targets; c) TLS Control Targets*

In order to combine data as well as ensure accuracy in the 3-dimensional space of objects. The dog well tower has a height of 50m, so there are some additional targets posted on the tower wall. Image control and inspection landmarks are located on the well tower wall marked with targets as shown in Figure 3c,

The coordinates of the focal points on the ground are connected by a Comnav T300 two-frequency GNSS machine (Accuracy: ground 10mm+0.5ppm; height 20mm+0.5ppm). When measuring, the machine is clamped with a sturdy mirror pole (Figure 4) and measured a minimum of 3 times. Wall decals are measured with coordinates using a Leica TS09 Plus electronic total station (length measurement accuracy 1.5mm+2ppm, angle measurement 1") with a mirrorless laser distance measurement program. Before use, the equipment is inspected to ensure compliance with technical specifications as prescribed.

Figure 4. *GCPs determination by GNSS/T300*

3.2. UAV Image Capture

The research area was captured using a DJI Phantom 4 Advanced (P4). The P4 is equipped with GPS and Glonass satellite positioning, and it features a 1-inch CMOS sensor with a 20MB resolution. Terrain analysis in Figures 1 and 2 reveals that the surveyed area has unique topography, including open pit mining areas (MO) and industrial yard (SCN). The UAV image capture method was determined as follows:

Despite having various ground features, including terraces and slopes, it was still possible to obtain complete point cloud data from the image capture. This is because the mining terraces have a relatively small height and always expand gradually from the center of the pit to the mining boundary. Therefore, when flying for image capture, a 75% overlap in both the vertical and horizontal directions was used. Typically, one ground location appeared in nine images. Different ground locations were captured from various angles due to the UAV's changing image capture positions during flight strips. Figure 5 illustrates different UAV image capture locations. Image capture location T1 was suitable for capturing orthogonal and oblique terrain features at positions b, d, and e, but it might not provide data for positions a and c. Conversely, positions T2 and T3 showed the opposite. With this principle in mind, it can be

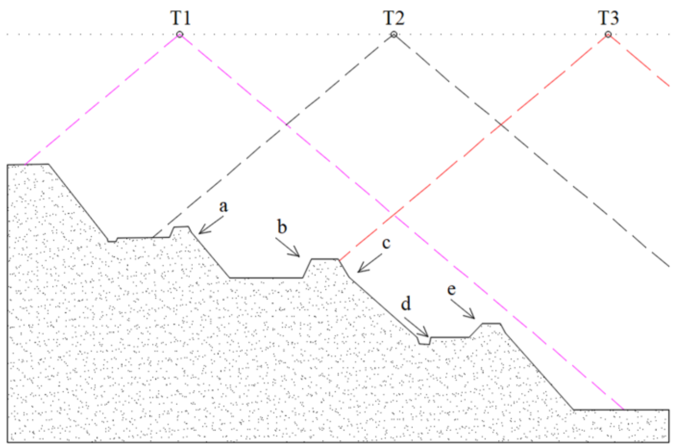

Figure 5. *Feature of open pit Mining Terrance*

seen that to establish a 3D model of the mining area, UAV image capture using the B1 orthogonal capture method (2D map) with the parameters listed in Table 1 is sufficient.

In general, the industrial yard (SCN) and specifically at the Nui Beo mining site are typically centered around the mine shaft entrance, which is where various mining industrial structures are located. Figure 6 illustrates that although the images were designed with a large field of view overlap (80%), due to the vertical nature of these structures, the self-obstruction by these structures with considerable height often results in inadequate field of view overlap at certain geographical positions, particularly on the walls and surfaces of these structures (Figure 6, positions L and R). This inadequacy in field of view overlap can lead to insufficient point cloud data at these positions if only the B1 image capture method is employed. Therefore, in the central area of SCN, additional image capture will be conducted using a grid-based image capture method (B2) with a 45-degree oblique capture angle.

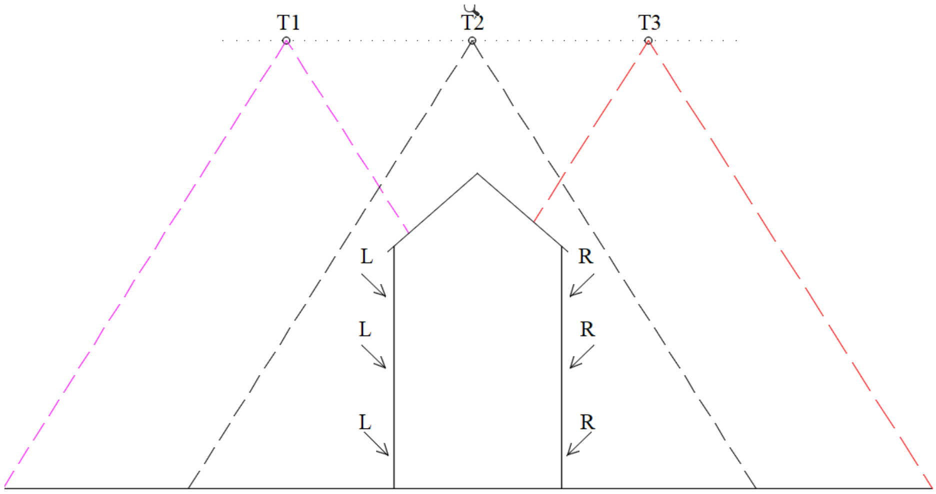

Figure 6. *Occurrence Potential of Ground object in UAV Images*

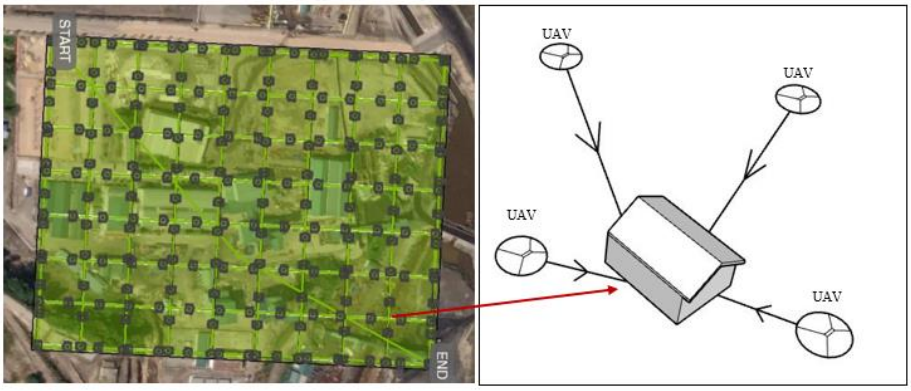

Figure 7. *UAV position for object capture using grid mission.*

With the B2 image capture method and the parameters listed in Table 1, each ground feature within the grid will have four images captured from four different directions (Figure 7) at a 45-degree oblique capture angle.

However, the shaft has a special structure, numerous small details, and is also the tallest structure in SCN35. To obtain a complete point cloud of the well tower for 3D modeling purposes, a circular flight method centered around the structure (B3) is applied to supplement the image capture of the well tower. The flight altitude varies from 50 m to 80 m, with two oblique capture angles of 45 degrees and 60 degrees. The parameters for these image capture methods are summarized and presented in Table 1.

Table 1. Flight plan options

Flight plan	Flight height (m)	Ground Sample Distance (cm)	Front and Side overlap	Capture angle
B1 (2D map)	100	2.74	75%x75%	90^o
B2 (Grid)	100	2.74	80%x80%	45^o
B3 (Circular)	50÷80	0.5	80%x80%	45^o and 60^o

When conducting the UAV image capture according to the designed methods, the takeoff location of the UAV is selected based on research [7] to ensure the required ground image resolution as per the design and to ensure the safety of the image capture equipment.

4. Building 3D Point Cloud

The UAV images captured using the B1, B2, and B3 flight methods are processed using Agisoft Metashape software. These images are processed simultaneously to obtain the best overall 3D point cloud (PC) result (Figure 8). The PC is established in accordance with the standard UAV image processing procedures, which include key steps such as image alignment, image correction, bundle adjustment, PC creation, and orthophoto generation, as well as the assessment of the accuracy of the achieved products.

Figure 8. *3D point cloud builded from UAV images*

The accuracy of the PC is assessed based on the Root Mean Square Error (RMSE) using control points within the model. The evaluation method and calculation formulas are referenced from the study by [8].

Table 2. The diffidence of Coordinate of Check Points

Name of point	The diffidence of Coordinate (cm)				Position
	ΔX	ΔY	ΔXY	ΔZ	
K2	-0.5	0.8	0.9	1.1	Shaft
K7	-1.5	1.8	2.3	-2	SCN ground
K9	0.9	1.7	1.9	1.8	
K23	-2.7	-1.5	3.1	-1.9	
K16	1.9	1.3	2.3	-2.5	Open pit mine
K20	-3.1	3.3	4.5	-4.2	
K22	-1.8	-1.5	2.3	-3.1	

The positional deviation of the coordinate points in the model is presented in Table 2. The root mean square error (RMSE) of the PC for the X, Y, and Z coordinate components are 2.0 cm, 1.8cm, and 2.6cm, respectively.

5. ESTABLISHING 3D MODEL

The 3D model of the experimental area is established at the level of detail LOD3. According to 3D format standards, the accuracy of the plan and height of the displayed object must reach 0.5m [9]. Objects with dimensions in three-dimensional space from 2x2x1m will be displayed.

The Industrial mining structures are digitized at various levels of detail, ranging from low detail (LOD0) to high detail (LOD3) based on the point cloud (PC). The dimensions of the structures can be directly measured on the PC, as shown in Figure 9.

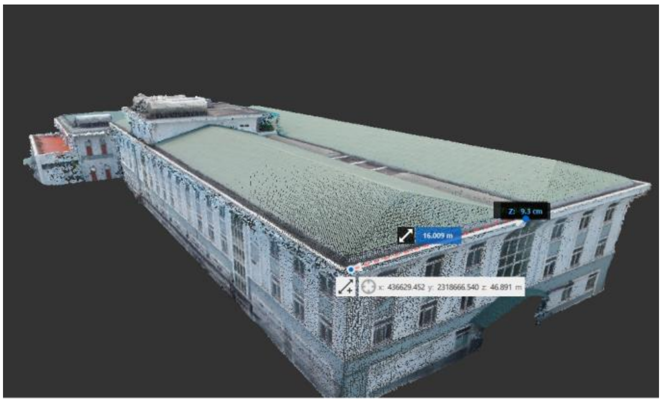

Figure 9. *Determining the dimensions of the structures on the PC*

For the open-pit mining area, the terrain points are extracted from the point cloud (PC) with a point density of < 0.5m. The contour lines and edges of the layers on the pit wall, along with distinctive points, are supplemented with coordinates taken from the PC. The overall PC data is input into SketchUp software, where a triangular TIN (Triangulated Irregular Network) model is automatically generated, creating a 3D surface (Figure 10).

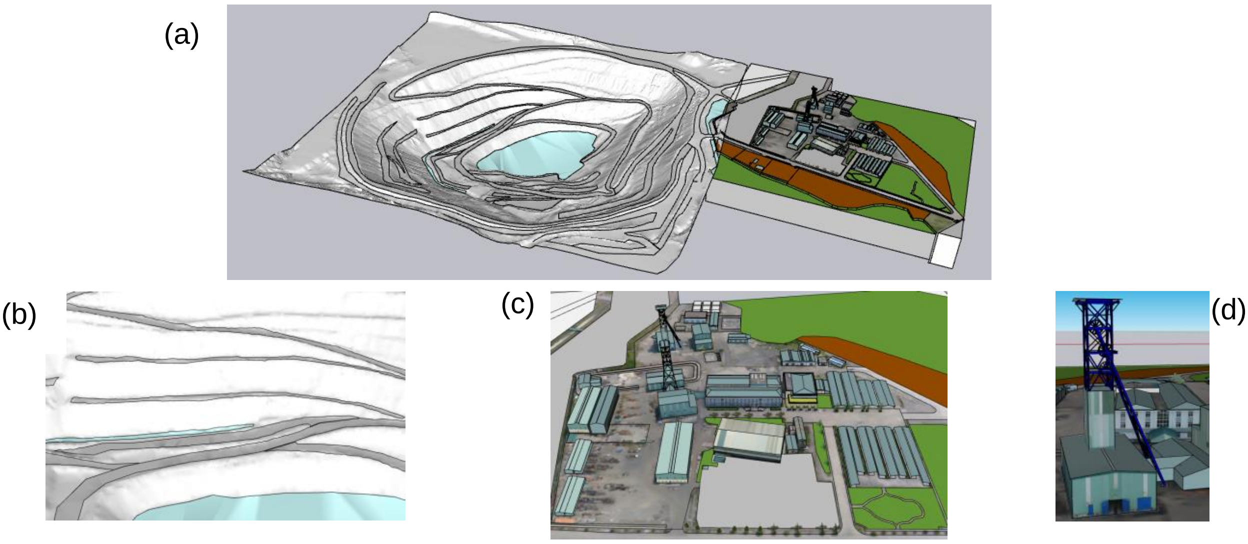

Figure 10. *3D model of the whole area*

a) Entire mining site, b) Working area, c) Mining industry yard, d) Shaft tower

The actual position of the objects is digitized on the orthographic image and referenced to the size on a PC. Pit mineral exploration includes objects such as road networks, mine infrastructure systems connected to the underlying terrain after being directly established on the 3D point cloud after noise filtering (outliers, equipment on the mine surface).

The terrain and geographical features are drawn using Sketchup Pro 2022 software. The results in Figure 10 illustrate the overall model, the Pit terrace area, the Central Processing Plant (SCN) area, and the model of the shaft.

6. RESULTS AND DISCUSSION

The UAV aerial photography method was designed with technical specifications as shown in Table 1, which were suitable for the actual conditions in the survey area. The results indicate that the combination of three flight plans, B1, B2, and B3, provided a complete 3D point cloud (Figure 8) with more details than each individual flight [5]. A high and comprehensive level of detail in the point cloud (PC) can be utilized to create a high-detail 3D model for both the industrial area and the open-pit mining site.

The root mean square error (RMSE) of the PC for both the horizontal and vertical components of the PC was less than 3.0 cm. The component coordinate deviations of the PC control points shown in Table 2 reveal that the positional error at the Pit terrace is greater than at the Central Processing Plant (SCN). The point K20 is located at the base of the Pit pit (corresponding to the greatest capture height), and it has the largest deviation. The industrial yard has a flat terrain, and the control points here have similar capture heights. Additionally, the inclusion of oblique images provides more complete PC data with smaller position errors in the Pit area (Table 2). Notably, point K2, located on the shaft tower, has the smallest deviation due to the addition of images captured along a circular path with a ground sampling distance (GSD) of 0.5 cm. Based on these evaluation results, in accordance with TCVN 16074:2015 standards, the established point cloud achieves the required accuracy for creating a 1:500-scale map corresponding to a LOD3 model.

The smallest identifiable object on the PC, necessary for modeling, is considered to be 1.5 times the ground sampling distance (GSD) [10]. The maximum GSD in the designed UAV photography is 2.74 cm, allowing for the identification of objects with a minimum distinguishable size of 4.11 cm. In theory, it is possible to model all geographical objects at the Central Processing Plant. However, the shaft tower has complex structures with many details smaller than 10 cm, making it impossible to directly measure and model these objects on the PC [3]. The 3D model of the shaft tower is created with objects larger than 20 cm in size.

7. CONCLUSION

The creation of a 3D model for the mining area, which includes the open pit mine, the industrial yard, and the shaft tower, requires a carefully calculated UAV aerial photography method to obtain a comprehensive point cloud and ensure economic and technical feasibility. For the Pit mineral excavation area, where there are minimal geographical features, orthogonal aerial photography is sufficient. In the central processing plant area (SCN), characterized by numerous construction structures, oblique angle images should be added, captured in a grid pattern. The shaft tower's complex structure, with many small details, allows for the measurement and reconstruction of objects larger than 20 cm using UAV data. Smaller details may require additional aerial photography or integration with other data sources, such as laser scanning.

In the process of creating the 3D model, the Pit mineral excavation can be directly reconstructed from the point cloud data after noise filtering. Geographical features within the SCN are reconstructed based on their real-world positions in orthographic images and measured dimensions on a PC.

However, the upper part of the shaft tower, with its intricate structure and numerous small details, can only be accurately measured, reconstructed, and modeled for objects larger than 20 cm using UAV data. Smaller details may necessitate additional aerial photography or the incorporation of alternative data sources like laser scanning.

ACKNOWLEDGMENTS:

This research was supported by The Ministry of Education and Training of Vietnam (MOET) under grant number B2022-MDA-10.

Conflicts of Interest: The authors declare no conflict of interest.

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Quyết định xuất bản số: 196/QĐ-NXBKHKT, ngày 11 tháng 12 năm 2023
ISBN: 978-604-67-2826-9
In xong và nộp lưu chiểu năm 2023.