МЕЖДУНАРОДНЫЙ

НАУЧНЫЙ ЖУРНАЛ

УСТОЙЧИВОЕ РАЗВИТИЕ ГОРНЫХ ТЕРРИТОРИЙ

Sustainable Development of Mountain Territories

ISSN 1998-4502
e-ISSN 2499-975X

"Земля - планета не простая".
А. де Сент-Экзюпери

Т.12
№4(45)
2020

INTERNATIONAL
SCIENTIFIC JOURNAL
"SUSTAINABLE DEVELOPMENT OF MOUNTAIN TERRITORIES"

The journal is included in the List of publications recommended by Supreme Attestation Commission (VAK)

The journal is included in the International Reference Database and Scopus citation System (quartile 3)

Address of the editorial office, founder, publisher:
44 Nikolaev Street, Vladikavkaz, RNO-Alania, 362021,
NORTH CAUCASIAN INSTITUTE OF MINING AND METALLURGY (STATE TECHNOLOGICAL UNIVERSITY)
Editorial Office of the journal "Sustainable Development of Mountain Territories".
Tel.: +7(918) 707-39-25,
+7 (8672) 40-73-60,
+7 (8672) 40-72-28.

Internet address:
http://www.naukagor.ru
E-mail: editor@naukagor.ru

The journal is registered in the Federal Service for Media Law Compliance and Cultural Heritage Protection.

Registration Certificate
PI No FS 77-27831 From April, 19 2007

Published since 2009 Is free
Editor MISIKOVA I.A.
Technical translation
PEYKAROVA N.I.
Computer design and make-up
PROVOTOROVA N.M.

Covering – 50 copies
Order No
Signed to print: 27.12.2020
Date of actual release:
30.12.2020
Printed by IE Fedoseev V. A.,
112 A Mechnikov st.
344013, Rostov-on-Don

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УДК: 528.7
DOI: 10.21177/1998-4502-2020-12-4-501-509

UAV PHOTOGRAMMETRY-BASED FOR OPEN PIT COAL MINE LARGE SCALE MAPPING, CASE STUDIES IN CAM PHA CITY, VIETNAM

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The use of lightweight Unmanned Aerial Vehicle with the aerial photogrammetry approach to construct the Digital Surface Model (DSM) has been effectively applied for various types of topography. However, the ability to carry out this approach for huge active open coal mines is insufficiently investigated, furthermore, the influences of topographical factors on the accuracy of DSM are ambiguous.
This experiment attempts to apply the UAV method for the two active coal mines with the total area of 7.99 km², exploited at a range from -300 m to 300 m altitude to figure out the effect of topographic factors on the accuracy of DEM constructed from UAV images. A total of 972 UAV images and 17 ground control points have been coupled to construct DSM of the mines. Besides, 16 checking points located at different elevations are used to evaluate the accuracy of DEM and to define the influence. DEMs are generated with the maximum RMSE of 0.086 m, 0.099 m, and 0.170 m corresponding to X, Y, and Z dimensional errors.
The results show the unclear correlation between the vertical accuracy of DEM and the relative elevation (R2=0.064), the general slope of the mines, and the number of ground control points using in the coal mines as well.

KEYWORDS:
Unmanned Aerial Vehicle, Digital Surface Model, open-pit mine accuracy, Cam Pha city.

Article received 28.09.2020

1. Introduction

Unmanned Aerial Vehicle (UAV) or Unmanned Aerial System (UAS) indicates an aircraft without a human pilot on board. Specialized cameras with a high-resolution, stable construction are designed to appropriately assemble on the UAV to carry out the missions related to the surface investigation. Primitively, UAV technology has mainly been used for military purposes, but it has been widely used in various industrial and academic domains. UAVs are characterized by the ability to reach high-risk, dangerous, and inaccessible areas without endangering human operators to implement tasks as disaster management [1], safety inspection on construction sides [2]. UAV integrated cameras is also a new photogrammetric measurement and mapping tool to complete or enhance the accuracy of the previous surveying and mapping methods [3; 4]. UAV photogrammetry produces results with higher accuracy than the existing via-photogrammetry or satellite imaging [5]. Moreover, UAV also has numerous advantages in the field of mapping compared to the traditional technologies such as high-spatial-resolution imaging, low-cost operation, and management; lightweight, easy to use and analyze data, abundant products (orthogonal images, DSM, DEM, and 3D models) [5–15].

The rapid development of UAV technology has brought many benefits to the mining industry in terms of safety, accuracy, and productivities. The UAVs are extensively applied in the open-pit mine areas. The air quality in a coal mine has been monitored using UAV in Vietnam [15]. In this study, sensors mounted on a UAV measured the variation of environmental variables as temperature, dust, CO_2, and NOx concentrated in the air of the mine. The multitemporal UAV images were used to measure the surface extent and volumetric excavation in the Sa Pigada Bianca mine [16]. One of the most popular applications of UAV techniques for open mines is the measurement and creating maps for managing and exploiting. UAV is the innovative monitoring techniques, which have been used to build DEM, DSM models [6; 9; 10; 13; 17]. These models are very important inputs for mining geodesy activities, such as monitoring mining subsidence and deformation surface [18–23], creation of terrain maps, 3D maps [5; 11; 14; 15], extracting terrain parameters for geomorphology, etc. In the open-pit mines, monitoring of topographic and volumetric changes through time shows great importance to the excavation process and management [24; 25]. It can be used to control the tripping ratio estimation and evaluate the costs of mining compared to the ore-derived profit. Furthermore, a local government also requires a highly accurate estimation of excavation volume to manage the environment and the tax regime [17].

Many other significant applications of UAVs in mining activities have been carried out: pit and dump management in mine using UAV technology [26]; stockpile management [27; 28]; mapping of inaccessible steep inclines and cliffs [29], monitoring and analyzing subsurface heating, geological modeling [30]. Most of these studies used lightweight UAV integrated simple cameras to generate DEM, DSM of mines with significant accuracy. However, the ability to carry out this approach for huge acitve open coal mines is insuficantly investigated, furthermore, the influences of topographical factors on the accuracy of DSM are ambiguous.

In Visetnam, there were several publications related to researches in open-pit mines using UAV drones, for example, quarries [14]. These mines are often small, easy to reach, and stable. In contracts, active open coal mines are characterized by located in rocky mountains, occupying a huge area, deep exploitation, steep slope, unstable ground, dense transportation, quick deformation, limited visibility due to the dust concentration in the air, etc. The difficulties of working in the field prevent surveyors from investigating the topography of the open coal mines even though the remote sensing or field measurement techniques are implemented. This study overcomes the challenges to construct DSMs of open coal mines using lightweight UAV images coupling ground control points (GCP). This approach is applied for three mines to evaluate the ability to use the UAV technique for such a special environment as an open coal mine. Besides, the effects of factors as slope, relative elevation, number of GCPs on the accuracy of DEM constructed by UAV imagery technique are assessed in the experiment.

2. Study area and methodology

2.1 Study area

This research utilized two study sites locates in Cam Pha city, Quang Ninh coal basin, North-East Vietnam, namely Cao Son, and Deo Nai (Fig 1). These sites are open coal mines that provide coal for the power plan and export. Each mine contains exploited layers characterized by various components bench height, bench face angle, catch bench, bench width, toe, crest bench, toe to crest slope. Generally, a catch bench is 5 m wide with a toe to crest slope of 55 degrees and a bench height of around 20 m. Coal is exploited in a catch bed and the useless materials such as rocks or soil are transported to the surrounding area which forms the topography of open mines with huge holes. Three coal mines are close together at the location of 21°01′00″N- 21°20′00″N latitudes and 107°18′15″E-107°19′20″E longitudes.

Cao Son mine occupies an area of about 3.3 km^2 with the highest point of 150 m above sea level and the bottom at the elevation of – 150 m. Deo Nai mine has an area of about 2.6 km^2 with an exploitation reserve of 42.5 million tons, and a fertility of 2.5 million tons a year (Vinacomin, 2015). These mines are exploiting by cutting down from the top, forming a steep rocky slope from 8 to 20 degrees. The continuous exploitation of coal, the unstable ground, and the transportation of rocky material prevent the surveyors from directly measuring the topography of the mines. Besides, the dense concentration of dust caused by the activities in the mines makes the difficulties in using remote sensing techniques to investigate the surface of mines.

3. Materials and research method

3.1. UAV system and Camera

In this work, the Phantom 4 pro with integrated camera and Inspire 2 with Zenmus camera was used to capture images. Both are quadcopter drone with four powerful rotors [http://blog.geekbuying.com/2016/11/

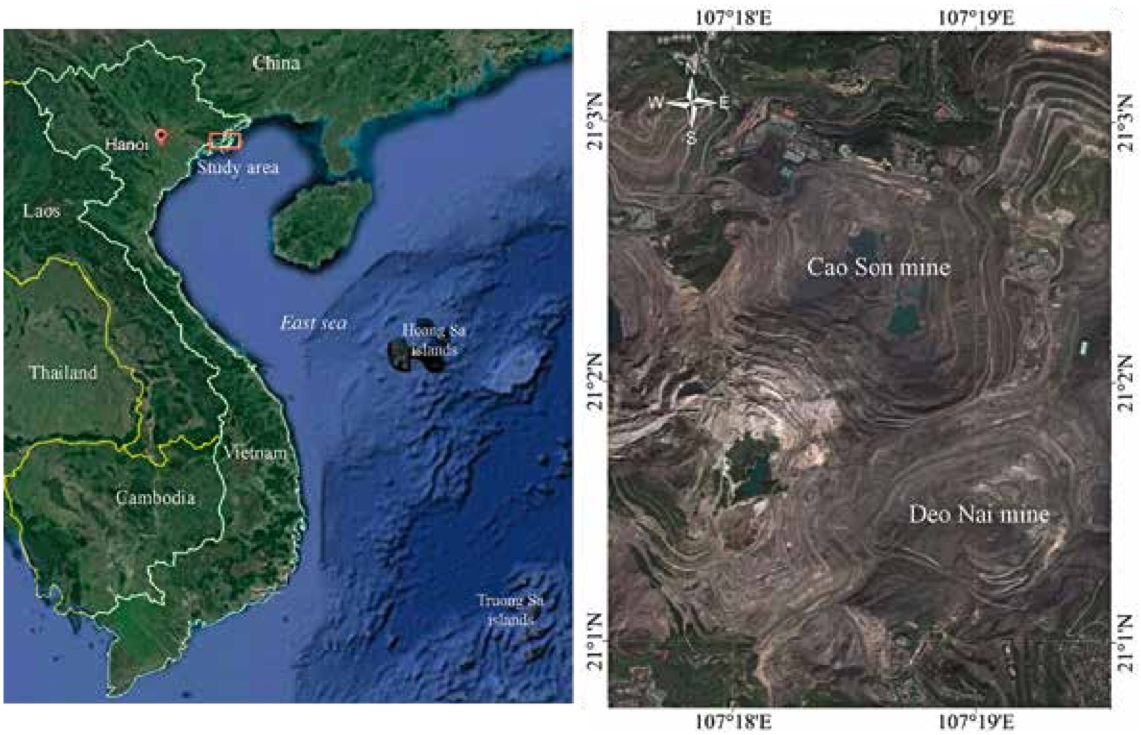

Fig. 1. *Location of investigating open-cast mines*

Table 1

Flying parameters

Specs name	Cao Son mine	Deo Nai mine
Number of images	544	428
Flying altitude	349 m	324 m
Ground resolution	9.55 cm/pix	8.92 cm/pix
Coverage area	4.43 km²	3.56 km²

dji-inspire-2-release-date-price-and-specifications]. The Inspire 2 and Phantom 4 Pro are capable of both automatic mode using the smart device applications and manual mode using the remote control. In the automatic flight mode, the parameters as the flight path, flight altitude, flight speed, overlapping of the photographs, etc., can be set before take-off. The two drones are attached to the GPS/IMU that enables it to take off and land with high stability automatically [31]. The Phantom 4 Pro is equipped with an integrated 20-megapixel RGB camera [32]. The ability flying time of Phantom 4 Pro up to 30 minutes, respectively, but it may reduce by some factors such as the wind, speed, and carried equipment.

3.2 Ground control placement and Image acquisition

Two main types of data are collected during the experiment compositing of measuring ground control points and flying UAVs to acquire images. The design of the GCP network and the plan for the flights must be primarily prepared before working in the field.

Ground control points were marked with highly reflective material for enhancing the contrast, the size of the marks was 60 x 60 cm, and it's large enough to easily detect GCPs in acquiring images. They were placed well distribution in the bottom, top, benches, and roads of mines. The number of GCPs was different in each mine, there are 15, 11, and 16 GCPs in Cao Son and Deo Nai, mine, respectively (Fig 2a, Fig 3a). Once all GCPs were placed the survey was performed. All GCPs are surveyed using GNSS/RTK technique and the GCP network is connected to the national coordinate stations with the VN2000 projection, WGS84 datum, Zone 48 N.

UAV images are acquired using the Phantom 4 pro in Deo Nai mine and Cao Son mine. The automatic flight mode was established using the Pix4D Capture application installed in an IOS smartphone, parameters such as the size of mapping areas, flight height, as well as endlap and side-lap of images are uploaded to the drone before the start. Weather conditions for data collection are the same in two mines, on sunny days with wind speeds of below 8 km/h. The flights are implemented in parallel lines crossing the mines with the front lap of 80% and side lap of 70%. The GCPs measurement and image acquisition are carried out in March 2020.

3.3 Image Processing and accuracy assessment

Image processing began with importing photos into Agisoft Photoscan. Photoscan is an advanced image-based solution for creating three-dimensional content from still images, it is produced by the Russian company Agisoft and in this work, it operates on windows 10-64 bit installed in laptop Dell 5520 precision with chip Xeon E, 32 Gb ram for image processing. Firstly, all photos of each mine were imported into one chunk, the next step, image alignment was performed where photos are aligned resulting in a sparse point cloud, the camera locations, and calibration parameters [33]. Next, the majority of scene details are built by applying Multiview stereo reconstruction on the previously aligned photos resulting in a dense point cloud. Finally, the mesh is generated and textured using the photographs [33].

In this project, both the horizontal and vertical assessments were carried out by comparing DSM with the GCPs measured by a GNSS/RTK in the term of Root Mean Square Error (RMSE). More specifically, assessments in easting (RMSEX), northing (RMSEY), vertical (RMSEZ), and all components (RMSEXYZ) were used, using equations as follows:

$$RMSE_X = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(X_{DSM} - X_{GCP})^2\right]} = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(\Delta X)^2\right]}, \quad (1)$$

$$RMSE_Y = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(Y_{DSM} - Y_{GCP})^2\right]} = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(\Delta Y)^2\right]}, \quad (2)$$

$$RMSE_Z = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(Z_{DSM} - Z_{GCP})^2\right]} = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}(\Delta Z)^2\right]}, \quad (3)$$

$$RMSE_{XYZ} = \sqrt{\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left((\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2\right)\right]}, \quad (4)$$

where and are the X-coordinate component of GCP and corresponding coordinate in DSM, respectively; and are the Y-coordinate component of GCP and corresponding coordinate in DSM, respectively; and are the Z-coordinate component of GCP and corresponding coordinate in DSM, respectively.

4. Research results

4.1 Cao Son mine case

For the case of Cao Son mine, with an area of 4.43 km^2, a total of 544 images were acquired through 6 missions. The point cloud of the mine with approximately 300 thousand points, was extracted according to the data processing method described above, and ground resolution (orthographic image) with resolutions of 9.55 cm. Besides, topographic contours at 5 m intervals could be extracted from the DSM. The orthophoto and topographic contour map are shown in Figure 2. For the model calibration, the RMSE of the position coordinates was analyzed to be about 1.221 cm and 1.638 cm in the North (X) and East (X) direction, respectively. The RMSE of 1.278 cm in the vertical (Z) direction. The detailed results are shown in Table 2.

Table 2 shows the coordinates and RSME of components at 7 checking points of the DSM in Cao Son mine. In general, the RMSE of the X component presents the highest accuracy with 0.063 m, the biggest error is found at the point CS12 with -0.165 m. The Z component shows the lowest accuracy with the RMSE of 0.170 m. Vertical error reaches to the maximum with 0.361 m at points CS5.

4.2 Deo Nai mine case

For the case of Deo Nai mine, with an area of 3.56 km^2, a total of 428 images were acquired through 5 missions. The point cloud of the quarry with approximately 200 thousand points, was extracted according to the data processing method described above, and an orthographic image with resolutions of 8.92 cm. Also, topographic contours at 5 m intervals could be extracted from the DEM. The accuracy assessment is shown in Table 4. The orthoimage and contour map is shown in Figure 3.

RMSE of checking points of DSM in Deo Nai is listed in Table 3. The DSM constructed with similar errors of X and Y components with 0.086 m, 0.049 m, respectively. However, the accuracy of the vertical component is almost double greater than the horizontal ones with the RMSE of 0.129 m. The critical error is found at the checking point DN16 with 0.244 m vertical error, but the best accuracy is seen at the point DN8 with -0.011m.

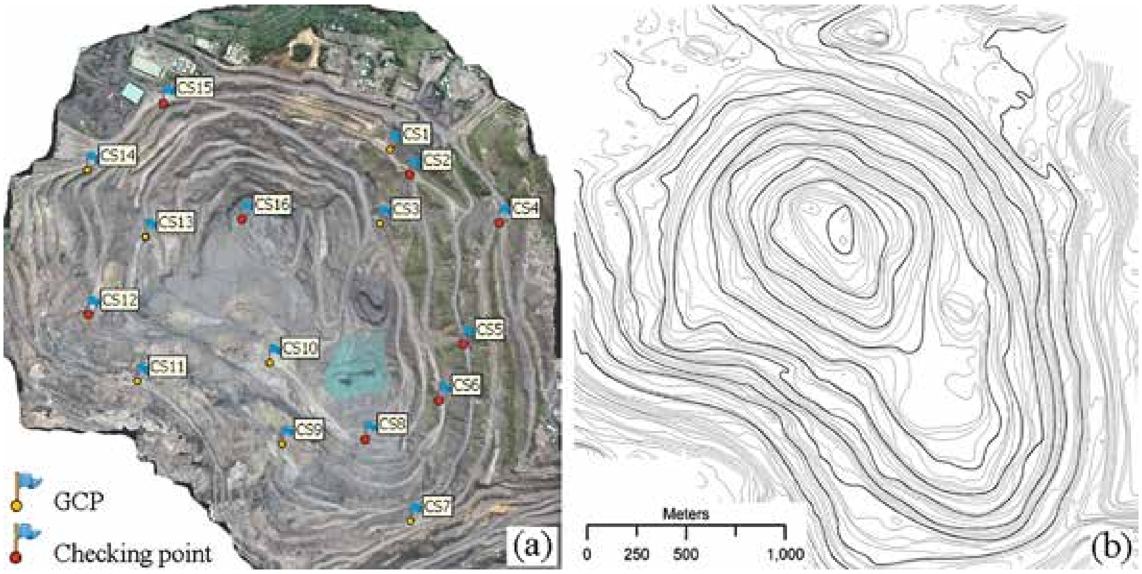

Fig. 2. *(a) Distribution of GCPs and checking points; (b) 5 m contour interval of Cao Son mine*

Table 2

Coordinates and RMSE of checking points in Cao Son mine

Checking points	*X* (m)	*Y* (m)	*Z* (m)	*X* error (m)	*Y* error (m)	*Z* error (m)	*XYZ* error (m)
CS2	454522.860	2327873.609	51.953	0.011	0.023	0.032	0.041
CS4	454870.650	2327673.533	135.808	0.008	-0.010	0.136	0.136
CS5	454732.882	2327194.050	73.805	0.027	0.113	0.361	0.379
CS6	454644.165	2326966.584	18.311	-0.039	0.127	0.042	0.140
CS8	454346.064	2326806.950	-24.545	0.005	0.113	-0.071	0.133
CS12	453231.072	2327312.298	49.723	-0.165	-0.068	-0.200	0.267
CS15	453532.256	2328164.421	39.143	0.046	-0.150	0.182	0.240
CS16	453836.675	2327710.044	-137.072	-0.010	-0.091	-0.046	0.103
RMSE				0.063	0.099	0.170	0.206

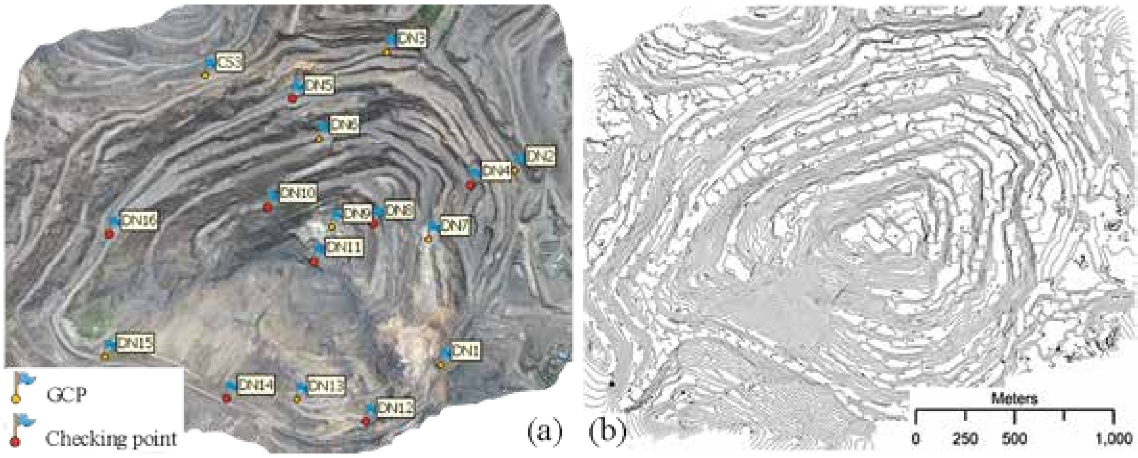

Fig. 3. *(a) Distribution of GCPs and checking points; (b) 5 m contour interval of Deo Nai mine*

Table 3

Coordinates and RMSE of checking points in Deo Nai mine

Checking points	*X* (m)	*Y* (m)	*Z* (m)	*X* error (m)	*Y* error (m)	*Z* error (m)	*XYZ* error (m)
DN4	455482.845	2326106.010	4.822	0.023	0.062	0.156	0.170
DN5	454833.741	2326415.103	51.500	-0.146	-0.021	0.108	0.183
DN8	455137.570	2325963.144	-103.023	-0.120	-0.001	-0.011	0.120
DN10	454742.036	2326025.983	-87.998	-0.087	0.049	-0.143	0.175
DN11	454915.419	2325820.997	-181.268	-0.021	0.080	-0.119	0.145
DN12	455099.895	2325245.329	38.588	0.091	-0.043	-0.053	0.114
DN14	454595.253	2325335.053	66.356	0.076	-0.049	-0.022	0.094
DN16	454174.124	2325927.990	63.784	0.014	-0.038	0.244	0.248
RMSE				0.086	0.049	0.129	0.162

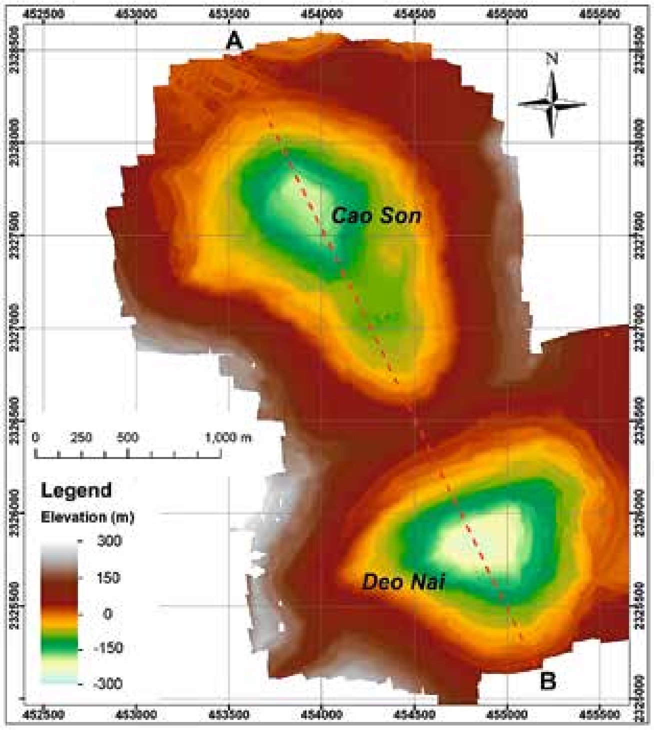

Fig 4. *Constructed DSM using UAV photos of the open mines*

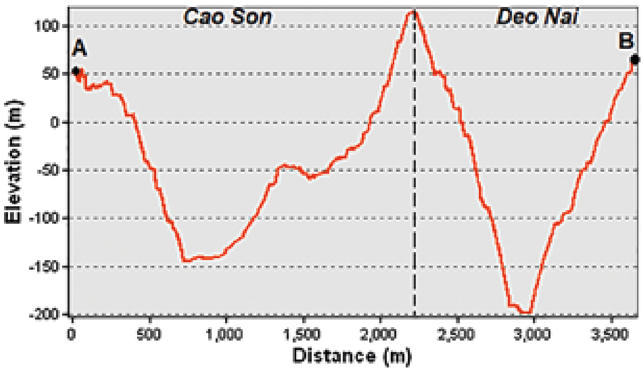

Fig. 5. *Elevation of the cross-section in the study area*

Figure 4 illustrates the continuous variation of the elevation of the coal mines. This model is the representation of the DSMs constructed by UAV images. The color histogram shows the elevation range from -300 m to 300 m corresponding the bottom to the top of mines. The slopes of mines are investigated using a vertical profile extracted from the map of DSM (Figure 5). The difference of slopes between Cao Son and Deo Nai mines can be observed thought the AB elevation profile.

4.4 Discussions of results

The implement of lightweight UAVs to investigate the topography has been popularly used in various studies. As an example, this work has completely constructed the DSM and orthophoto of three open coal mines. However, the quality of the constructed DSM needs to discuss more in such a particular environment as the open-pit coal mines. There are 33 GCPs have been surveyed in the study area, in which 16 GCPs are checking points. The discussion focuses on these checking points to evaluate the accuracy of DSM.

It is proved that the increase in the number and the even distribution of GCPs improves the accuracy of DSM constructed by UAV photos [34]. However, the trend is right for the horizontal dimensions but the vertical error seems to be a disagreement [35; 36]. This experiment is an example supporting the above assertion. The horizontal errors in this study are relatively similar in the mines, the vertical error is almost double compared to the others. Besides, the use of 8 GCP in Deo Nai, and 8 GCPs in Cao Son produces DSM with corresponding vertical errors of 0.129 m, and 0.170 m (Figure 6). The great number of used GCPs does not improve the vertical accuracy of DSMs.

Thus, this section vestigates the vertical error of DSM in the correlation with the factors as the elevation of checking point, the topography, absolute flight height. The checking points in the study area are located at different layers of elevation from the bottom to the top of mines with an elevation range of 360 m. It is seen that the elevation of checking points does not relate to the vertical accuracy of DSM due to the insignificant correlation with R2 of 0.064 (Figure 7). The lowest checking points located at -181 m (DN11) and -137 m (CS16) even represent the small vertical error with several 0.145 and 0.103 centimeters, respectively. In contrast, the checking points with the lowest vertical accuracy of 0.361 m at the point CS5 in Cao Son is seen at the top of mines with an elevation of 73.8 m.

The flight height is a factor controlling the accuracy of DSM and orthophoto. Conventionally, the camera captures images with a higher resolution at shorter flight high than that of a higher flight height. UAV is set to fix flight high at around 300 m above the sea level. The maximum perpendicular distance between the camera and the bottom of the mine is 500 m and between the camera and the top of the mine is around 200 m. In this case, the resolution of photos at the tops of mines is double better than that of the bottom. However, there are no significant variation of accuracy between checking points at the bottom and the top of mines. Even though the effect of flight high on the accuracy of DSM is not well exhibited in the frame of this experiment, the flights are recommended to design at different altitudes according to the variation of terrain.

Deo Nai has been exploited at the layer of -230 m which formed topography with a steep slope of around 19 degrees (Figure 5). Inversely, the DSM with a lower slope of 9 degrees in Cao Son represents the significantly higher errors comparing to the others. The variation of the general slope shows the unclear correspondence of the accuracy of DSM in this investigation.

The coordinates and the accuracy of every point in DSM are influenced by the surrounding GCPs using in processing UAV photos. In other words, the even distribution of GCPs may minimize the error of DSM. Thus, this work investigates the effect of the distances between checking points and surrounding GCPs on the accuracy of checking points. The checking points DN11 and DN16 located at the bottom and the top of the Deo Nai mine with the elevation of -181.268 m and 63.784 m, have vertical errors -0.119 m and 0.244 m, respectively (Table 3).

The opposite variation between the vertical error and the elevation of DSM may relate to the decrease of vertical errors according to the increase of distances from the surveying point to the nearest GCPs. DN16 is surrounded by the thee closest GCPs CS3, DN15, and DN9 with the average distance of 649 m counted from them, which is double longer than that of the checking point DN11 (361 m) calculated from the closest GCPs DN6, DN7, and DN9. Similarly, in the cases of checking points CS12 and CS16 in Cao Son mine, the average distances from 3 closest GCPs to CS12 and CS16 is 536 m and 439 m, respectively, may cause the lower accuracy of DSM at the top of the mine than the one at the bottom. The effect of surrounding GCPs on the accuracy of DSM is observed in this study; however, this relation should be investigated more in a future study [37–41].

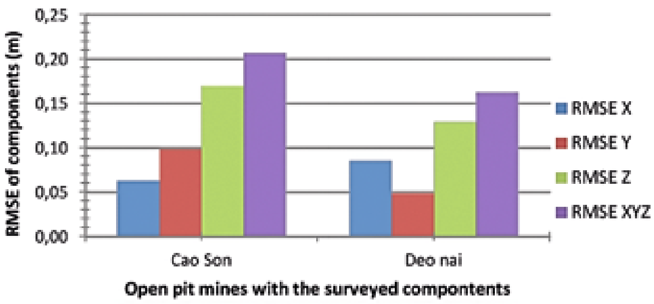

Fig. 6. *RMSE of checking points in two open-pit mines*

In sum, the accuracy of DSMs constructed from UAV photos may be affected by various factors. The comparison of thee DSMs constructed in two open coal mines indicates the insignificant correlation between the accuracy of DSMs and the flight altitude, the general slope, the relative elevation in this study. The ambiguous variation of error may be random due to the complicated topography and the weak reflectance of optical radiance at the black surface of a coal mine as well.

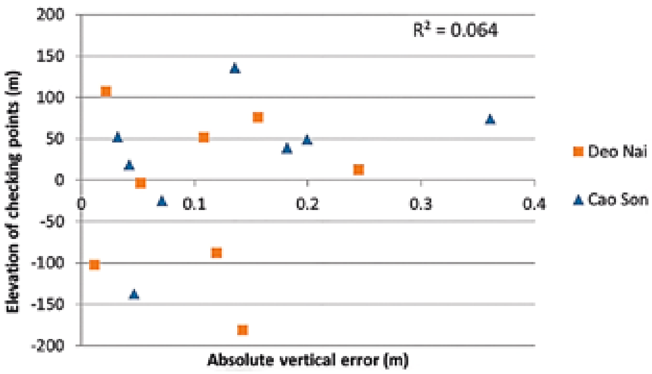

Fig. 7. The correlation between elevation and the absolute error of elevation of the DSM

5. Conclusion

The investigation of the topology of active open mine is always a challenge due to the unstable ground, rocky steep slope, high intensity of dust which affect the accuracy of ground measurement using optical instruments. UAV technique is an appropriate method, in this case, regarding the accuracy, safety, time, and money efficiency. The experiment of using the UAV aerial photogrammetry approach in this study in the open coal mines proved the above assertion. DSMs are generated at a very high horizontal accuracy with the cm level. The vertical error is, as usual, a bit higher than that of horizontal error with a 0.17 m RMSE in Cao Son mine. The effects of the slope of mines, the elevation, and the flight height on the accuracy of DSMs are insignificant in the frame of the study, the influence of the designed flight path on the quality of DSM should be evaluated in the future research. In general, the quality of the constructed DSMs adapts the requirement of the accuracy of topographical investigation of open coal mines that confirm the ability to use lightweight UAV for such a huge, complicated target as mines in this study.

The method of using UAV images combined GCPs to construct DSM may be applied for other open mines, however, a new technique that integrates the RTK receiver on board of UAV may be more effective and it should be tested in the future works.

ACKNOWLEDGEMENT:

This work was financially supported by the Ministry of Education and Training (MOET) in Vietnam under grant number B2020-MDA-14.

CONFLICT OF INTEREST:

The authors declare no conflict of interest.

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БЕСПИЛОТНАЯ ФОТОГРАММЕТРИЯ В КРУПНОМАСШТАБНОМ КАРТОГРАФИРОВАНИИ ОТКРЫТОЙ УГОЛЬНОЙ РАЗРАБОТКИ НА ПРИМЕРЕ г. КАМФА (ВЬЕТНАМ)

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DOI: 10.21177/1998-4502-2020-12-4-501-509

Использование легкого беспилотного летательного аппарата (БПЛА) с подходом аэрофотограмметрии для построения цифровой модели поверхности (ЦМР) эффективно применяется для различных типов топографии. Однако возможность реализации этого подхода для огромных действующих угольных шахт недостаточно исследована, кроме того, влияние топографических факторов на точность ЦМР неоднозначно.

В этом эксперименте предпринимается метод БПЛА для двух действующих угольных шахт с общей площадью 7,99 км^2, эксплуатируемых на высоте от -300 м до 300 м, чтобы выяснить влияние топографических факторов на точность ЦМР, построенной с данным изображений беспилотного летательного аппарата.

В общей сложности 972 изображения с БПЛА и 17 наземных контрольных точек были связаны для построения ЦМР в шахте. Кроме того, 16 контрольных точек, расположенных на разных отметках, используются для оценки точности матрицы высот и определения влияния. ЦМР генерируются с максимальным среднеквадратичным отклонением 0,086 м, 0,099 м и 0,170 м, соответствующими ошибкам размеров по осям *X, Y* и *Z.*

Результаты показывают нечеткую корреляцию между вертикальной точностью DEM (цифровая модель высоты) и относительной высотой (R^2 = 0,064), общим наклоном шахт, а также количество наземных контрольных точек, используемых на угольных шахтах.

Ключевые слова: беспилотный летательный аппарат, цифровая модель поверхности, точность карьера, город Камфа.

Статья поступила в редакцию 28.09.2020.