Low Altitude Photogrammetry for Urban Road Mapping

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ABSTRACT

To manage road over the country, geometry data of road is needed for decision making and project well management. The primary data is usually contributed by field technical support persons, such as surveyor, engineer, and others for conventional method of survey. For the sake of life safety, a study aims to carry out mapping work with unmanned aerial vehicle (UAV) platform and photogrammetry-based method. This study proposed an urban road mapping with optimal flight parameter, sensor parameter and GCP distribution by flying low for detail texture acquisition of road. The primary product of photogrammetry based is accurate digital orthophoto model (DOM) and digital elevation model (DEM). The flight parameters, sensor/image parameter of unmanned aerial vehicle (UAV) including focal length effectiveness (10.26mm and 3.61mm), image end lap percentage (90%, 80%, and 70%), Ground Scale distance (GSD) (3cm, 2cm, and 1cm), and ground control point (GCP) distribution setup (pyramid square-, square-, and linear-based networks) were outlined. In this study it was found that longest focal length 10.26mm is suitable for road mapping. 70% end lap with 1cm GSD or 25m altitude is the best parameter. By increased and well distribute GCP over the project area, accuracy increased by 1% of position. Optimal network of GCP is pyramid based network. Photogrammetry-based mapping was an accurate method for detail road mapping by proposed result above.

Received: 30/10/2020
Reviewed: 18/1/2021
Accepted: 25/1/2021

Keywords: *Road, Mapping, UAV, 3D Reconstruction, Flight Parameter*

INTRODUCTION

The main product of photogrammetry is digital orthophoto model (DOM) and digital elevation model (DEM). Drone has undoubtedly eased survey method with a specific accuracy level by boosting data in excellent time and long-range mapping. However, many researchers faced the challenge of reconstructing DEM and DOM products for better accuracy, camera calibration procedure, and most importantly, variable on flight and sensor parameter. Plus, it yields different results of accuracy by using different flight settings onto interest mapping object for example, spot level, city modelling, forestry area, slope, river and road reserve. Therefore, this study stressed on flight parameters including side study of sensors parameters for roads mapping.

Various studies, had proposed various flight parameters for mapping a specific feature. Different flight parameter setting could fit various feature/object interests to be mapped, such as slope mapping (Khairul Nizam Tahar & Ahmad, 2013), flat area (Tonkin & Midgley, 2016), city modelling (Junqing, Zongjian, Xiaojing, & Yongrong, 2012), agriculture (Tsouros, Bibi, & Sarigiannidis, 2019; Saberioon & Gholizadeh, 2016), forestry (Seifert et al., 2019) and others.

Flight parameters limited to flight altitude and rate of end lap and side lap of image for each strip line. While sensor/ image parameters refer to focal length of camera, GSD and image overlapping rate in image alignment (Howell, Jensen, Petersen, & Larsen, 2020). Others condition affected DOM and DEM product is GCP distribution. Most studies diversified the altitude of unmanned aerial vehicle (UAV) to find the optimal accuracy of check point (Howell, Jensen, Petersen, & Larsen, 2020; Ali &

Abed, 2019; Tahar, 2015). Others changed the end lap and side lap of image percentage (Jawak, Wankhede, & Luis, 2018; Seifert et al., 2019; Ali & Abed, 2019; Zhou, Lin, Gui, & Xie, 2012). Meanwhile, for difference feature mappings, Saad and Tahar (2019) proposed 10m optimal altitude for road defect mapping, which was proven by error analysis and Junqing et al. (2012) used a stereo camera at 300–400m altitude to map Shanxi City with 0.21m and 0.35m of horizontal and vertical errors respectively.

GCP purpose to give absolute position of photogrammetry product. K.N. Tahar, 2013 study on different GCP configuration and GPS observation data and proposed 80m flight altitude with 0.691m horizontal error and 9 GCP requirement for slope mapping. The checkpoint error can be decreased when more GCP is established (Sanz-Ablanedo, Chandler, Rodríguez-Pérez, & Ordóñez, 2018). However, optimal distribution GCP is prioritize. Less is more. Equation 1 and Equation 2 describe relation of flight altitude to the ground sample distance (GSD) and pixel size calculations, respectively. Different focal length has different GSD value even fly at same altitude.

$$GSD = \frac{H}{f} * \mu \qquad \text{Eq. 1}$$

Where,

GSD = ground sampling distance
H = flying height
f = focal length
μ = pixel size

$$\mu = \frac{W}{SW} = \frac{H}{SH} \qquad \text{Eq. 2}$$

Where,

μ = pixel size
W = width of camera sensor,
SW = horizontal number of pixels for W
H = height of camera sensor
SH = vertical number of pixels

End lap percentage setting gives more image overlap for photo alignment. Overlap is an amount of one photograph that includes the area covered by another photograph in which the overlap area is expressed as a percentage. The photo survey minimum overlap, especially for digital image needs to acquire 80% end lap and 30% side overlap (Zhang, Xiong, & Hao, 2011). Equation 3 describes the degree of overlap formula derived from flight planner. Since this study used micro-UAV, the wind turbulence can affect the overlap by dragging the drone from its flight line. Therefore, the sensor/image parameters, such as image overlap degree, deflection angle, and aerial photograph height are not sufficiently stable (Li & Li, 2014).

$$degree\ of\ overlap = \frac{Px*Py}{Lx*Ly} * 100 \qquad \text{Eq. 3}$$

Where,

Px & Py = width and height of the image overlap area
Lx & Ly = width and height of the image

The feature matching depends most on the corresponding feature searching at different images. Therefore, to ensure accuracy and efficiency, image overlap percentage setting is crucial. Altitude affects the Ground sampling distance (GSD) of image. GSD is the distance between two consecutive pixel centres measured on the ground. The higher the altitude, the lower the spatial resolution of image. The GSD is directly proportional with UAV altitude. As the height increases, so does the GSD value (Figure 1). While, by certain height can cover a certain ground dimension/footprint. Ground footprint could be determined from Equation 4 or Equation 5.

$$ground\ dimension = \mu * \frac{f}{H} \qquad \text{Eq. 4}$$

$$ground\ dimension = SI\ x\ S \qquad \text{Eq. 5}$$

Where,
SI = size of images
S = scale of photograph

Meanwhile, the pixel size is derived from Equation 6.

$$\frac{x}{X} = \frac{f}{H} \qquad \text{Eq. 6}$$

Where,
x = distance of object in pixel
X = distance of object on ground

The same outcome can also be derived from multiplying the photo scale with image dimension (height for end lap and width for side lap). Ground dimension can solve the percentage of end lap value.

$$percent\ end\ lap = \frac{C-B}{C} x100 \qquad \text{Eq. 7}$$

Where,
C = footprint dimension (height or width of image on the ground)
B = distance between exposure station

The objectives of this study are to determine the flight parameter, sensor parameter and GCP distribution to produce accurate DEM and DOM road. The study used GSD value 3cm, 2cm and 1 cm as constant value of analysis. Thus, each UAV fly at derived flying altitude from equation 1. This study hypothesized, lowest altitude and high overlap image (90%) will yield higher accuracy regardless of flight time and massive data storage. Because high resolution with small GSD value gives less error of displacement and more common point features are tie together with corresponding point features during align photos. Meanwhile, the best GCP network is a pyramid-based shape network because it has well distributed point including one centralize point control (5 GCPs).

MATERIAL AND METHODS

In this study, a setting on flight parameters were set on site using DroneDeploy apps. The system is user friendly and simplifies the calculation of GSD and flight time/speed by proposing the default parameter setting as present in Introduction. Table 1 show a type of parameters involved in this study. Sensor parameters test used 2 UAV which carry out in two different places. Each UAV fly at an altitude to achieve desired GSD value at 3cm, 2cm and 1cm. Thus 6 different altitude study were carried out. Figure 1 illustrates the workflow of parameters involved in this study. RMSE accuracy analysis will justify the variable of parameters. RMSE is indicates the absolute fit of the model to the data. Model acquire from GPS observation while data from photogrammetry processing. 10.26mm focal length UAV fly at Taman Wahyu, Kuala Lumpur, while 3.61mm Focal Length UAV fly at Shah Alam, Selangor (Figure 3). Both were road area with an area of 2 Ha. UAV used with respective focal length is Phantom 4 and Mavic 2 Pro. Table 2 show a specification of UAV used.

Table 1: Types of parameters involved in this study

Sensor parameter	Focal length	3.61mm	GSD = 1cm, 2cm and 3cm	Altitude (m) = 20, 60, 90
		10.26mm		Altitude (m) = 25, 65, 100
Flight parameter	Altitude	Based on GSD value		
	End Lap	70%, 80% and 90%		
GCP	Distribution	Linear, square and pyramid-based network		
Analysis	Accuracy	RMSE		

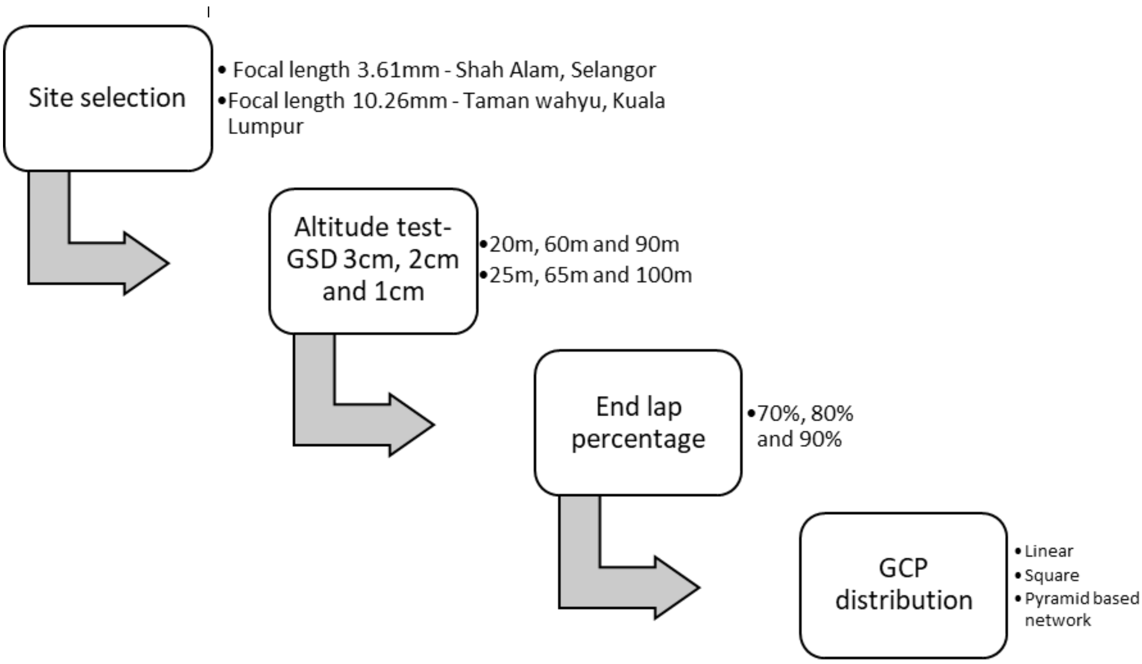
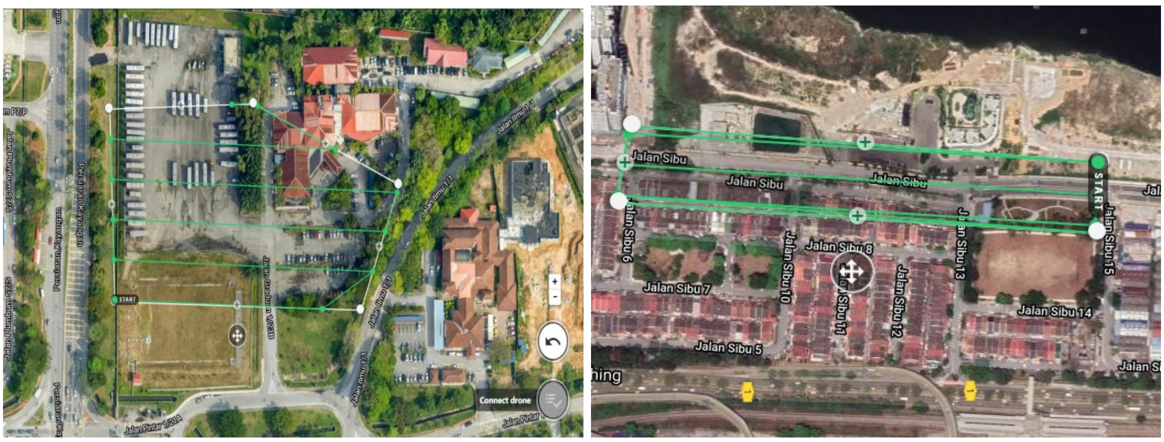


Figure 1: Flowchart of the study



(a) (b)

Figure 2: Flight line of the study areas; a) Universiti Teknologi MARA, b) Jalan Sibu, Taman Wahyu, Kuala Lumpur

Table 2: UAV's Image specification

UAV	Pixel Size (micron)	Sensor $_W$ (mm)	Sensor $_H$ (mm)	Sensor Size Width	Sensor Size Height	Image Resolution
Phantom 4	1.6	6.4	4.8	4000	3000	12
Mavic 2 Pro	3.16	17.3	11.53	5472	3648	20

GCP was established using Trimble R8s, with MyRTKNet system from known GPS point with 2minute observation. GCP was well distributed based on shape to create a positioning network for photogrammetry model. Figure 3 show three basic networks of GCP distribution.

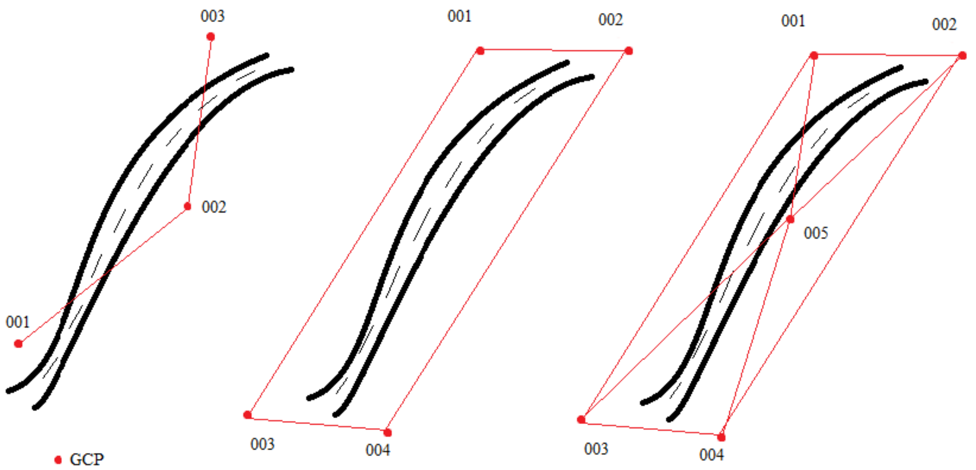


Figure 3: GCP networks; linear- (left), square- (middle), and pyramid square-based (right) networks

RESULTS AND ANALYSIS

The result covered accuracy of check point from Orthophoto product based on different flight parameter, sensor/image parameters and GCP distribution. Table 3 show result of RMSE for UAVs flight parameters and sensor parameters. Data process using 4 GCP well distribute. While, figure 4 show a bar chart of RMSE separately for different focal length. Bar chart show a RMSE value for easting(E), northing(N) and height(H), meanwhile, dotted line indicate vector of displacement of EN and ENH. Analysis will focus on EN vector and ENH vector. Displacement of checkpoint from its original position is visualized.

Table 3: RMSE value of study

	GSD	1cm			2cm			3cm		
	MAVIC 10.26mm	**70%**	**80%**	**90%**	**70%**	**80%**	**90%**	**70%**	**80%**	**90%**
RMSE (m)	E	0.471	0.493	0.537	0.576	0.447	0.488	0.414	0.514	0.576
	N	0.525	0.543	0.444	0.439	0.475	0.49	0.685	0.576	0.556
	EN	0.705	0.733	0.697	0.724	0.652	0.692	0.800	0.772	0.801
	H	2.783	2.298	2.476	0.332	2.849	0.17	2.873	3.255	0.943
	ENH	2.871	2.412	2.572	0.797	2.923	0.712	2.982	3.345	1.237
	P4 3.61mm									
RMSE (m)	E	0.491	0.538	0.732	0.769	0.758	0.806	0.532	0.432	0.525
	N	0.655	0.632	0.55	0.479	0.5	0.371	0.922	0.947	0.911
	EN	0.819	0.830	0.916	0.906	0.908	0.887	1.064	1.041	1.051
	H	4.706	4.154	4.01	1.238	4.472	1.03	9.95	7.216	9.899
	ENH	4.777	4.236	4.113	1.534	4.563	1.359	10.007	7.291	9.955

Lowest RMSE EN value of Mavic is 0.652m recorded at 2cm GSD with 80% end lap. Lowest RMSE EN value of Phantom 4 is 0.819m recorded at 1cm GSD with 70% end lap. Highest RMSE EN value of Mavic is 0.8m at 3cm GSD with 90% end lap. Highest RMSE EN value of Phantom is 1.064m at 3cm GSD with 90% end lap. The accuracy of the result is different due to the different GSD and flying altitude. the sensitivity of camera lens to the road features is reduced when it captured away from slope. 90% end lap record high RMSE because error accumulate by high image overlap.

Lowest RMSE ENH value of Mavic is 0.712m recorded at 2cm GSD with 90% end lap. Lowest RMSE ENH value of phantom 4 is 1.359m recorded at 2cm GSD with 90% end lap. Highest RMSE ENH value of Mavic is 3.345m at 3cm GSD with 80% end lap. Highest RMSE ENH value of Phantom is 10.007m at 3cm GSD with 70% end lap. This result shows a low RMSE acquire for 90% end lap image. Thus, indicate a low H value acquired which compensate to high value of EN of respective group.

The coverage area is reduced when focal length is increased. Therefore, a suitable focal length must be use for road mapping job. In this study it was found that longest focal length 10.26mm is suitable for road mapping. 70% end lap with 1cm GSD is the best parameter. Study use selected parameter for GCP distribution study. It was tested for 3 types of GCP network.

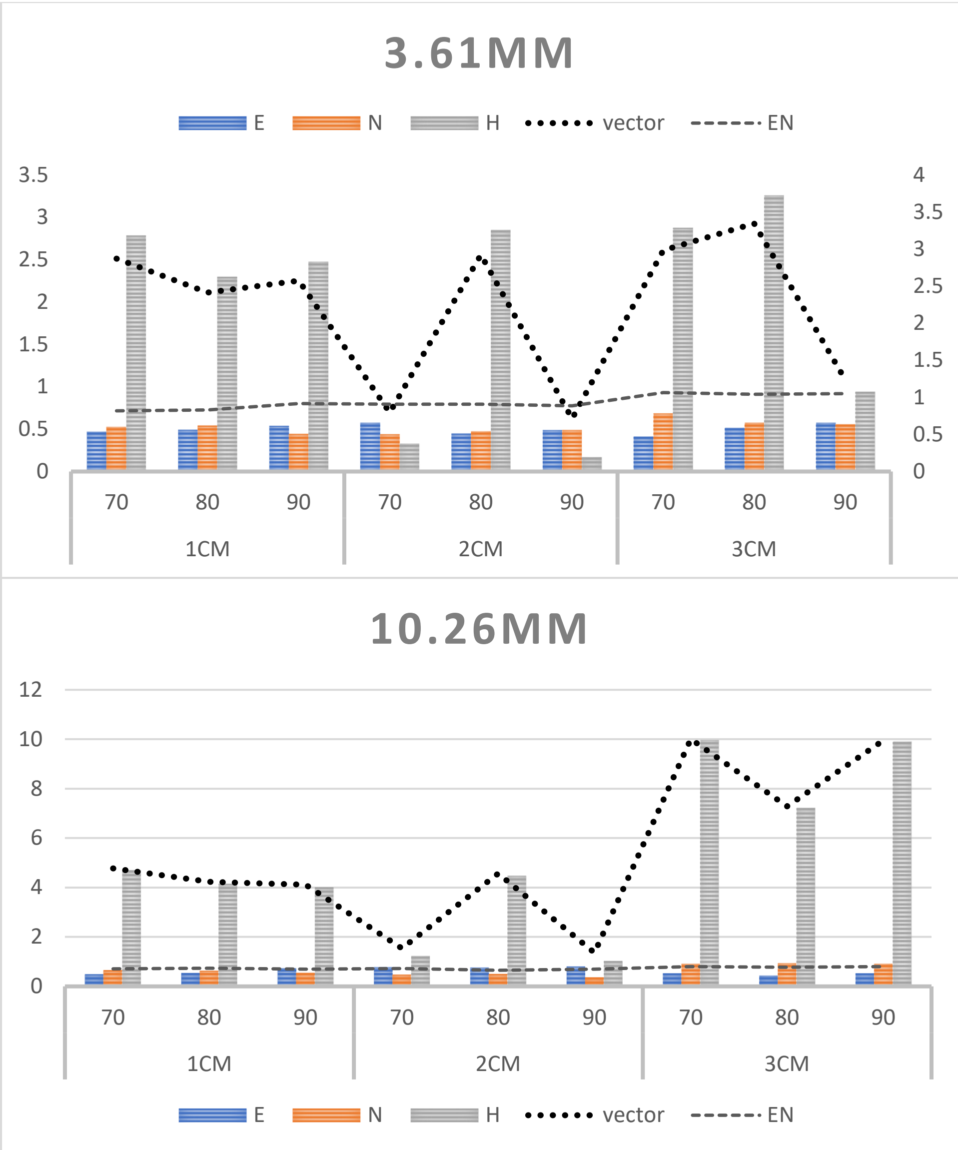


Figure 4: Accuracy assessment of UAVs

Table 4 show a GCP distribution shape-based network. Result show pyramid-based network have lows E, N and H value from all tested GCP network. However, it is okay to use linear or square network unless, well acquaint about tolerance of error for our job and what is the useful of the product for.

Table 4: GCP distribution shape- network

	linear	square	pyramid based
E (m)	0.498	0.471	0.421
N (m)	0.54	0.525	0.473
H (m)	2.85	2.783	2.19

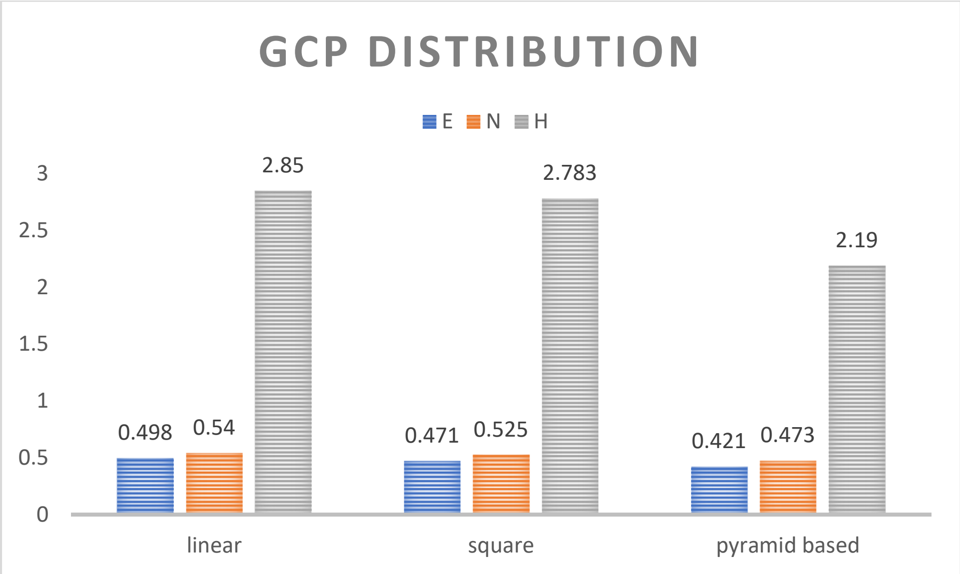


Figure 5: Checkpoint accuracy from different GCP distribution

CONCLUSION AND FUTURE WORK

Photogrammetry-based mapping was an accurate method for road mapping. Due to its high maneuverability in congested area and non-invasive technique, it provided ease with accuracy guarantee for surveyor. High correlation was observed between altitude and end lap image percentage, focal length sensor, and shape-based GCP network in which it positively affected RMSE value. However, care should be exercised in areas of more topographic variation which does not extremely affect accuracy since the maximum slant of road available is not more than 10°. Additionally, photogrammetry is a suitable and reasonable method to map a wide and long road reserve with accuracy guarantee.

The coverage area is reduced when focal length is increased. Therefore, a suitable focal length must be use for road mapping job. In this study it was found that longest focal length 10.26mm is suitable for road mapping. 70% end lap with 1cm GSD or 25m altitude is the best parameter. GCP had increased the accuracy of map. By increased and well distribute GCP over the project area, accuracy increased by 1% of position. Based on the analysis section, each network contributed errors in photogrammetric block. Optimal network of GCP is pyramid based network.

Further research is necessary to determine suitable methods for modelling road defect structure. The study included flight parameter from multiple altitude image captures to combine large and mini scales of features (pothole). Broad scale could provide effective time and cost to map road alignment and area deterioration. Therefore, complimenting the two-way photogrammetry product derived from different resolutions is vital.

ACKNOWLEDGEMENT

Faculty of Architecture, Planning, and Surveying Universiti Teknologi MARA (UiTM), Research Management Institute (RMi) and Ministry of Higher Education (MOHE) are greatly acknowledged for providing the fund BESTARI 600-RMC/DANA 5/3/BESTARI (TD) (006/2019) to enable this research to be carried out. The authors would also like to thank the people who were directly or indirectly involved in this research.

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