Geospatial-Based Slope Mapping Studies Using Unmanned Aerial Vehicle Technology

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Abstract Unmanned Aerial Vehicle (UAV) is one of the geospatial-based data acquisition technologies which acquire data within a short period for slope mapping studies. Geospatial-based UAV mapping are widely used in many applications, specifically for scientific and mapping research. The capabilities of rapid data acquisition and accessibility to slope risk area are several advantages of using UAV technology. However, the accuracy that influences the output of slope mapping studies using UAV technology need to be considered such as flying altitude and selection of the optimum numbers of Ground Control Points (GCPs). This study focuses on the reviews of geospatial-based UAV mapping, others geospatial-based technologies as well as accuracy assessment of its output. Several considerations were discussed in the production of slope map using UAV technology namely determining the optimum number of GCPs and flying altitudes, as well as evaluating of UAV images. This study presents the production of high resolution slope map area that has been conducted at Kulim, Kedah, Malaysia as the slope location

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prone to landslide occurrences. Multi-rotor UAV known as DJI Phantom 4 was used for collecting the high resolution images with various flying altitudes. The result of X, Y and Z coordinates show that the accuracy is influenced by the flying altitude of UAV. As for flying altitude is increased, the accuracy of slope mapping is improved. Moreover, the analysis indicated that the slope area coverage and the number of tie point increases as the UAV altitude level also increases.

1 Introduction

Geospatial is defined as the relative position of objects on the earth's surface (Collin English Dictionary 2012). All related earth surface measurement including drone mapping and monitoring are classify as geospatial-based work. Drone or Unmanned Aerial Vehicle (UAV) normally attached with set of digital camera that can record the scene or object of interest. Photogrammetry offers advance mapping technology to measure and produce 2-Dimension (2D) and 3D geospatial-based mapping without touching the object.

According to Forlani et al. (2015), photogrammetry can be define as a science of extracting metric information which is position of image surface points. One of major use of photogrammetry is to measure object or scene from images taken at long distance by UAV. There are many UAV photogrammetric applications being used recently, for instance; topography, crop monitoring, coastal monitoring, landslide monitoring. Geospatial-based slope mapping is one part of the applications that can be employed by UAV. But how does the accuracy of altitude level affect the accuracy of slope map? This study will elaborate the analysis of the three different altitude levels.

2 Slope Monitoring

A slope area is associated with the height of an area where as it becomes higher thus the steeper is the gradient. The risk of landslides may occur when the height of the slopes increases and becomes unstable (Knapen et al. 2006). Landslide is one of the disasters related with unstable land condition that can lead to property damage and death. Landslide is a geological incident which includes most of the earth's movements, such as falling rocks (Hungr et al. 1999; Trappmann et al. 2014), and slope failures (Arnold et al. 2015; Hori and Tamate 2018).

There are several factors that causes landslides such as: (a) gravity acts on the slope (Reis et al. 2016); (b) erosion by rivers, glaciers, or sea waves which produce steep slopes (Blyth and de Freitas, 2017); (c) sloping rock or land slopes due to saturation by heavy rain; (d) an earthquake that produces tensions causing weak slopes to collapse; (e) volcanic eruptions produce ash, heavy rain, and trash flow; (f) tremors from machines, traffic, explosives, even thunder may trigger tremendous

Fig. 1 Example of landslide area

collapse; (g) extreme weight resulting from the accumulation of rain or snow, stacks of rocks or ores, from garbage dumps, or man-made structures that put pressure on weak to heavy cracks and other structures; (h) Groundwater pressure acts to make the slope unstable on shallow soils, deep-rooted plantings that bind colluvium to base stones. These factors can affect a slope condition in long-term if not monitored regularly. The main thing that needs to be done is monitoring the slope area that prone to landslide incidence (Fig. 1 shows example of landslide area at Johor, Malaysia).

3 Geospatial-Based Slope Mapping

Geospatial-based Slope mapping is one of the approaches to monitor slope area where the generated maps can be combined with geology inputs and environmental engineering of an area. The slope map is intended to be frequently produced for landslide mapping as a reference material for stakeholders such as developers, researchers and local authorities. There are several technologies that have been used for Geospatial-based monitoring and mapping of slope area such as satellite imagery (Bagnardi et al. 2016), Light Ranging and Radar (LiDAR) (Dunham et al. 2017), Terrestrial Laser Scanner (TLS) (Francioni et al. 2014; Tahar 2015), manned aircraft, Total Station, Mobile Laser Scanner (MLS) (Michoud et al. 2015), Global Positioning System (GPS) and drone. Table 1 shows the summary of the comparison between these technologies.

Table 1 The summary of the comparison from various geospatial-based technologies

Technology	Flight planning	Flight restriction	Cost estimation	Production rate	Coverage area	Accuracy
Satellite imagery	–	Tropical region cover with cloud	Up to ten thousand	Depend on satellite	Large area	Up to m
LiDAR	More complex	Less impact from weather	Up to hundred thousand	Can be automated, faster	Large area and not practical for small area	Up to cm and can be mm
TLS	No	No	Up to hundred thousand	Can be automated and faster	Limited coverage	Up to cm
Manned aircraft	Overlap and side lap need to be considered	Must fly during day time and need clear sky	Up to hundred thousand	Time consuming	Large area and not practical to cover small area	Up to cm
Total station	No	No	Up to thousand	Time consuming	Limited coverage	Up to mm
MLS	No	No	Up to hundred thousand	Can be automated and faster		Up to cm
GPS	No	No	Up to thousand	Can be automated and faster	Limited coverage	Up to mm
Drone/ UAV	Overlap and side lap need to be considered	Fly during day, clear sky time and under cloud	Up to thousand	Can be automated and rapid	Cover small and large area based on endurance	Up to cm

All these technologies have its specific capabilities and limitations which were used to produce slope map. For example, satellite imagery has potential for covering large area with different image resolution, however, most of the images in tropical region are covered with cloud (Al-Tahir et al. 2011). For LiDAR technology and manned aircraft, both requires huge budget reaching up to hundred thousand Dollars but provide accurate map. Meanwhile, total station required a lot of time and manpower from fieldwork until map production (Tahar 2015). Furthermore, this technique only measure bearing and distance on the earth's surface which impractical for performing fast and cost saving projects. Figure 2 shows the platforms and sensors that usually used for slope and landslide survey, which were used by Geospatial Imaging and Information Research Group (Gi2RG), Universiti Teknologi Malaysia (UTM), Johor, Malaysia.

Fig. 2 Platforms and sensors that usually used for slope and landslide survey

Moreover, laser scanning either mobile or terrestrial are techniques used for obtaining 3D coordinate data and capable to scan high-density data of an object or surfaces. GPS is used for obtaining 3D coordinates with accurate result but limited in mapping application. Presently, UAV is often used and become more popular as a monitoring and mapping application since it can provide map data in a short time. UAV applications recently have widely been used in many studies. Table 2, Figs. 3, and 4 shows UAV-based application and other sensors that used by many researches that utilize UAV and other sensors for slope and landslide survey and mapping.

Initially, the UAV was introduced for military and surveillance purposes. With the advancement of technology and instrumentation surveying, the importance of using UAV has been seen by researchers, surveyors and practitioners. By using photogrammetry concept, mapping application can provide up to sub-centimeter accuracy. Photogrammetry concept has been introduced since 1990 which divided into close range, aerial and terrestrial photogrammetry.

UAV photogrammetry was introduced by Henri Eisenbess in year 2009 through his study for capturing images of cultural heritage using close range photogrammetry concept. As one of the geospatial data acquisition technologies, UAV can be used to monitor the slope of the area experiencing instability. It is believed that this technology can be used in producing high resolution images and also can speed up the process of getting information on the incident.

In producing slope mapping, the most important part is getting the accurate result for detecting the changes of the slope area. According to Tahar (2013), number of ground control points and flying altitudes are the most important aspect need to be consider during data acquisitions. These two aspects can influence the accuracy of the produced map. Therefore, this study presents the production of high

Table 2 Some research utilize UAV and other sensors for slope and landslide survey and mapping

Published article	Drone	Photogrammetry	LiDAR	Total station	GPS
Lucieer et al. (2014)	/	/			/
Uysal et al. (2015)	/	/			/
Kršák et al. (2016)	/	/		/	
Kumar et al. (2018)	/	/			/
Tung et al. (2018)	/	/			/
Fuad et al. (2018)	/		/		/
Fugazza et al. (2018)	/	/	/		/
Rossi et al. (2018)	/	/			/
Agüera-Vega et al. (2017)	/	/		/	/
Francioni et al. (2018)	/	/	/		/
Yeh et al. (2018)	/	/			/
Xiang et al. (2018)	/	/			/
Cahyono and Zayd (2018)	/	/		/	/
Zieher et al. (2018)	/	/	/		/

Fig. 3 Total station in slope model study

Fig. 4 GPS survey used for landslide mapping

resolution slope map using UAV technology. The research involved the following steps, (i) preparation of field work (i.e. determination of the flying altitude) and the flight mission; (ii) processing and evaluating of UAV images, and (iii) production of slope map.

4 Applications of UAV

UAV technology become popular all over the world due to its rapid development and people awareness on the importance of UAV usage especially among surveyors, researchers, government agencies and other organizations. An aerial image is an output obtained from UAV technology which used in the field of mapping and remote sensing. Digital camera or any sensors attached to UAV used for capturing object on the earth's surface accordance to the flight path. Digital camera can be attached either in horizontal or vertical based on the purposes of study.

There were several studies have been conducted in mapping and monitoring using UAV such as cultural heritage (Eisenbeiss et al. 2005), urban planning (Spatalas et al. 2006), 3D modelling (Remondino et al. 2011), coastal (Darwin et al. 2014; Gonçalves and Henriques 2015), landslide (Everaerts 2008), river mapping (Ahmad et al. 2013; Alho et al. 2009) and others.

The advantage of UAV is able to mount different types of sensors and items for various applications. In addition, the use of UAV reduces human risk, cost and manpower which are suitable for project that involve with risky or disaster areas. UAV also is widely used in the agricultural sector to evaluate the soil conditions, identifying pests that attack soil, soil mapping or spreading seeds, pesticides and water (Krishna 2016). All UAV applications either in mapping or non-mapping fields requires different method, accuracy and standard of procedure.

5 Accuracy Assessment of UAV Mapping Studies

Some researches applied the mapping technique for specific purposes while other researches were done to determine the behaviour of the data collection and result obtained. Some studies focuses in different level mapping accuracy, UAV camera calibration, and also the effect of the Ground Control Point (GCP) distribution and numbers. Below are some studies and findings that have been done for UAV mapping application including slope mapping.

Throughout the research have been done by Agüera-Vega et al. (2017), the Ground Control Points (GCPs) affects the mapping accuracy and the findings are to choose 15 GCPs rather than 20 GCPs as the accuracy are quiet similar at 120 altitude level, and the map accuracy are increase from 4 GCPs until 15 GCPs. The optimum number for the research is 15 numbers of GCPs.

There are also other research from Udin and Ahmad (2014), based on the finding for experiment done at altitude levels of 40, 60, 80, and 100 m, sub-meter accuracy achieved by the (Root Men Square Error) RMSE value decreases when the altitude levels or flying altitude increased.

There also researches have been done to assess the calibration altitude levels for photogrammetric UAV mapping such as by Yusoff et al. (2017). Based on the finding, the optimum calibration parameters is at 25 m camera distance for the best mapping accuracy at 1.5, 15 and 25 m UAV mapping. The camera distance for calibration and UAV mapping are correlated and the optimum camera parameters are needed for high accurate mapping.

Based on Tahar (2013), the photogrammetric block for GCPs configuration shows the mapping accuracy behavior in order to produce the best photogrammetric products. In the study, two main photogrammetric results were produced namely digital orthophoto and digital elevation model. The result stated that various configurations recorded coefficient percentage of more than 97% accuracy for the six configurations. The research concluded that GCPs affected the photogrammetric block to acquire the accurate photogrammetric results such as slope mapping using photogrammetric drone. In this study, eight and nine CCPs configurations are the best configurations.

6 Significant of Study

Some applications do not concern with the accuracy and only require the overview of the area. Moreover, most of the projects are handled by UAV mapping practitioner usually involves small areas where the use of UAV technology is practical. Geospatial-based high resolution aerial images also can be obtained using UAV technology where it can fly with low flying altitude and under cloud cover.

7 Study Area

The study area is situated in Kulim, Kedah, Malaysia (Fig. 5) where three different altitude levels and numbers of GCPs were performed. The main factor for this research was conducted at Kulim, Kedah, Malaysia due to the condition of slope in that area is prone to the landslide incidences. The geospatial-based slope mapping produced in this study based on the data collection conducted in November 2017.

Fig. 5 Study area site at Kulim, Kedah, Malaysia

8 Instrumentations

8.1 DJI Phantom 4

Rotary wing UAV known as DJI Phantom 4 was used in this study. DJI Phantom 4 was equipped with gimbal, vision system, camera, remote controller, charger, live view and intelligent flight battery. This DJI Phantom 4 has an advanced stereo Vision Positioning System (VPS) which make it able to fly precisely, easier and safer without satellite positioning. Table 3 shows details specification of DJI Phantom 4.

8.2 Camera

In this study, digital camera was used and attached at the DJI Phantom 4. The camera has a megapixel of 12.4 and other specification as shown in Table 4. It has four (4) blades in which two blades rotate in clockwise direction and another two blades rotate in counter-clockwise direction. The DJI Phantom 4 is more stable and safe to be used for outdoor and indoor activities, especially in the urban area and it

Table 3 DJI Phantom 4 specification

Specification	Detail
Weight	1380 g
Diagonal size	350 mm
Max ascent speed	S-mode: 6 m/s
Max descent speed	S-mode: 4 m/s
Max speed	S-mode: 20 m/s
Max tilt angle	S-mode: 42° A-mode: 35° P-mode: 15°
Max angular speed	S-mode: 200°/s A-mode: 150°/s
Max service ceiling above sea level	19685 feet (6000 m)
Max wind speed resistance	10 m/s
Max flight time	Approx. 28 min
Operating temperature range	32° to 104°F (0° to 40 °C)
Satellite positioning systems	GPS/GLONASS
Hover accuracy range	Vertical: ±0.1 m (with Vision Positioning) ±0.5 m (with GPS positioning) Horizontal: ±0.3 m (with Vision Positioning) ±1.5 m (with GPS Positioning)

is capable to capture images from certain altitude. Figure 6 show DJI Phantom 4 with remote controller and camera attached.

8.3 Global Positioning System (GPS)

Based on the article by Geomatics World (2017), generally, there are three methods on ways to achieve high geospatial-based accuracies for UAV mapping:

1. Combining image data with Ground Control Points (GCPs)
2. Correcting position information by means of post-processing kinematic (PPK) systems
3. Correcting position information by means of real-time kinematic (RTK) systems

In this study, static observation of GPS was used for ground control points (GCPs) establishment. This observation technique only takes around 20–30 min per point. In addition, this technique can provide millimeter accuracy for absolute orientation or exterior orientation and to perform aerial triangulation. This GPS instruments is the combination of a compact form factor, revolutionary universal tracking technology, and multiple communication methods. The Topcon GR-5

Table 4 Camera specification

Specification	Detail
Sensor	1/2.3” CMOS Effective pixels:12.4 M
Lens	FOV 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
ISO range	100–3200 (video) 100–1600 (photo)
Electronic shutter speed	8 - 1/8000 s
Image size	4000 × 3000
Still photography modes	Single shot Burst shooting: 3/5/7 frames Auto exposure bracketing (AEB): 3/5 bracketed frames at 0.7 eV Bias Timelapse HDR
Video recording modes	UHD: 4096 × 2160 (4 K) 24/25p 3840 × 2160 (4 K) 24/25/30p 2704 × 1520 (2.7 K) 24/25/30p FHD: 1920 × 1080 24/25/30/48/50/60/120p HD: 1280 × 720 24/25/30/48/50/60p
Max video bitrate	60 Mbps
Supported file systems	FAT32 (≤ 32 GB); exFAT (>32 GB)
Photo	JPEG, DNG (RAW)
Video	MP4, MOV (MPEG-4 AVC/H.264)
Supported SD cards	Micro SD Max capacity: 64 GB Class 10 or UHS-1 rating required
Operating temperature range	32° to 104°F (0° to 40 °C)

Fig. 6 DJI Phantom 4

receiver is the most popular and versatile option for high precision GNSS reliability where it capable to tracking GPS, GLONASS, BeiDou, Galileo, QZSS constellations. Figure 7 shows the static GPS observation using Topcon GR-5.

Fig. 7 CPs establishment through GPS observation

9 Research Methodology

In this study, the research methodology involves three main phases, namely data acquisition, data processing and data analysis. The DJI Phantom 4 was flown at three different flying altitudes such as 20, 40 and 60 m. Figure 8 shows the research method is done.

Minimum of five (5) GCPs numbers is required for the image processing software. The details explanations of fieldwork preparation, processing and evaluating UAV images and production of Slope Map are discussed in the next sub sections.

10 Preparation of Field Work and the Flight Mission

Image acquisition is an important step that needs to be completed in order to get the best aerial images. The flight planning needs to be settled before capturing the aerial images. Several considerations need to be clarified during flight planning such as flying altitude, coverage of the study area, focal length, scale, percentage of the end and side lap. In real site image acquisition, the important part depends on weather and time taken for aerial images on the study area which could affect the brightness of images. For the two real sites of study area, the best time to acquire aerial images is about from 8.00 am until 11.30 am in the morning.

Two people were put in-charge during the flight mission namely the pilot and the ground crew. In this study, autonomous micro rotary wing UAV for image acquisition was implemented for flight mission and landing. In the autonomous mode, micro rotary wing UAV received input from laptop or mission planner via radio modem and was flown based on the starting waypoints until the end of waypoints. However, an operator must be alert at all time to avoid accident during the flight mission (Tahar 2013).

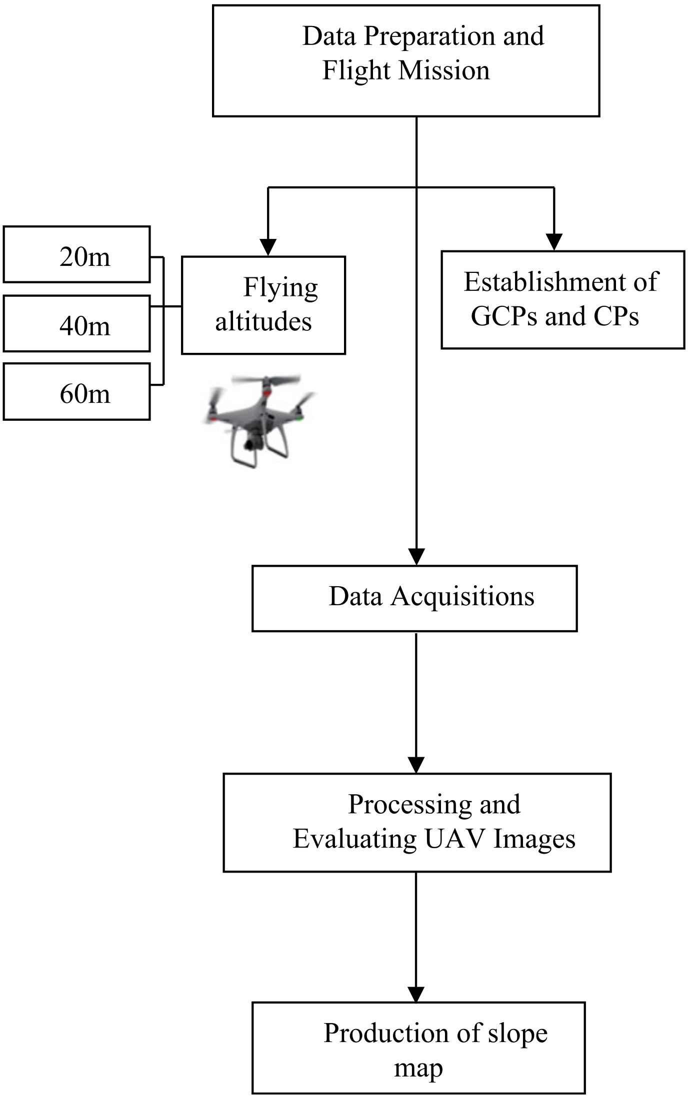


Fig. 8 Research methodology

11 Processing and Evaluating of UAV Images

Data processing was carried out after the required data were acquired successfully. In this study, the data processing involved the following; (a) The collected data were processed by using ArcGIS software to produce map either in softcopy or/and hardcopy; (b) The GCPs and CPs obtained from ground survey measurement (i.e.

Fig. 9 Distribution of GCPs and CPs of the slope area

total station and GPS rapid static technique) were processed to obtain the 3D coordinates of these points. Figure 9 shows the distribution of GCPs and CPs of the slope area.

12 Production of Geospatial-Based Slope Mapping

This stage was conducted after performing the processing and evaluating of UAV images. There are two geospatial-based slope mapping produced in this study namely, orthophoto and (Digital Elevation Model) DEM mapping of slope area. Figures 10, 11 and 12 shows the produced orthophoto based on three different flying altitudes. Meanwhile, Figs. 13, 14 and 15 shows the produced DEM based on three different flying altitudes.

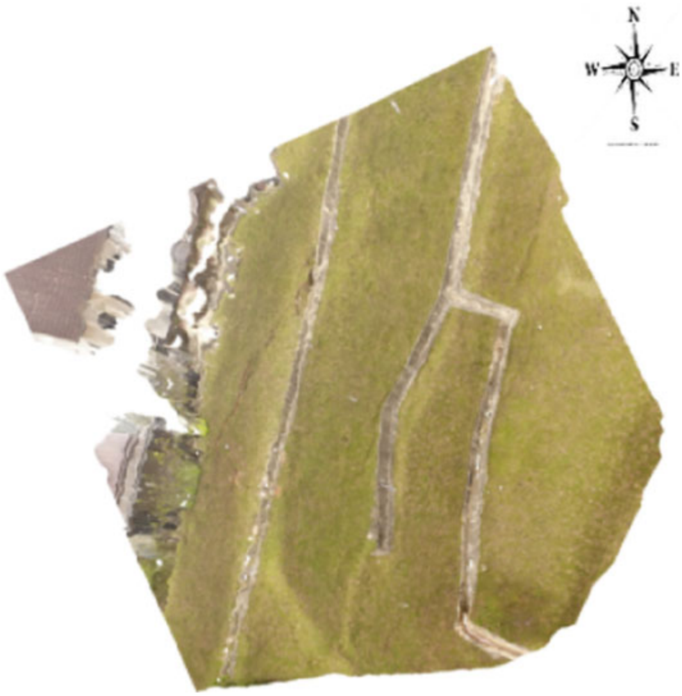


Fig. 10 Orthophoto for flying altitude of 20 m

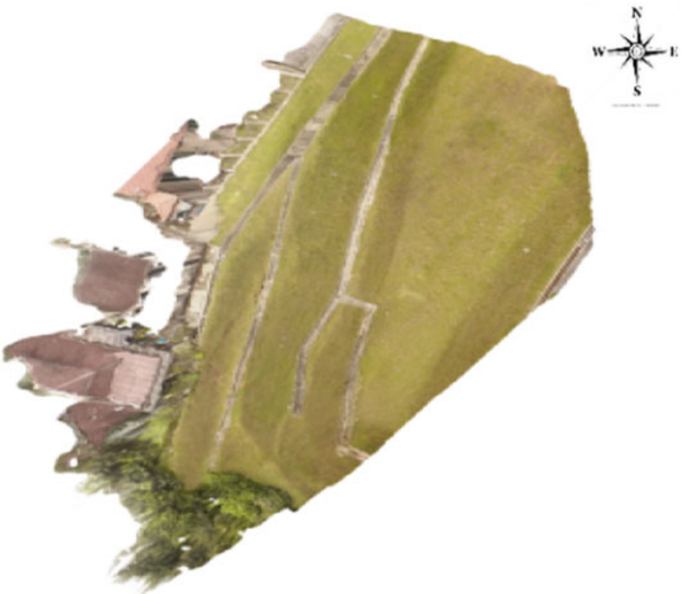


Fig. 11 Orthophoto for flying altitude of 40 m

Fig. 12 Orthophoto for flying altitude of 60 m

13 Result and Analysis

There are two main results produced in this study, namely orthophoto and digital elevation model (DTM). Both of the results contains horizontal and height coordinates which can be used to give information of movement points of the slope area. Orthophoto and DEM results contain X, Y and Z coordinates. Figures 10, 11 and 12 illustrates the orthophoto of the produced slope area after through image processing step. Orthophoto specifically contain horizontal coordinate which gives provides clear images with high resolution and up-to-date information; in other words, data on demand can be produced by using the micro UAV.

Meanwhile, Figs. 13, 14 and 15 shows the DEM of the slope area which gives height information where the brown and magenta colour represents the highest and lowest value for three different flying altitudes respectively. The DEM shows the different highest and lowest value.

The lowest value of the slope area are 56.849 m, 56.363 m and 46.472 m at 20 m, 40 m and 60 m flying altitudes, respectively. Whereas, the highest value of the slope area are 84.042 m, 72.104 m and 68.804 m at 20 m, 40 m and 60 m flying altitudes, respectively. Based on Fig. 16, it was identified that the flying altitudes influenced the error of the aerial images. The error of the map is decreased when the flying altitudes increased. It represents all the error of X, Y and Z below

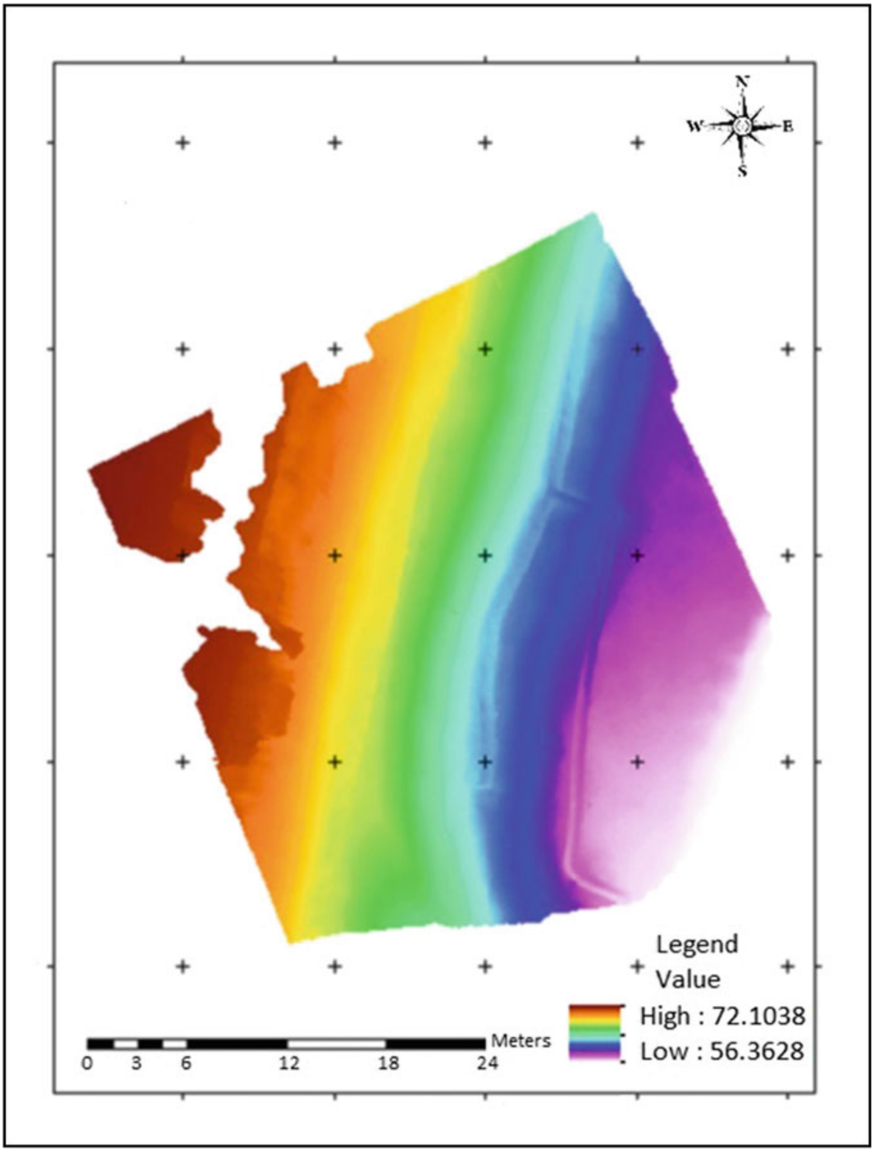


Fig. 13 DEM for flying altitude of 20 m

one (1) meter. Figure 17 shows the relationships between number of tie points, coverage area and flying altitudes. The coverage area and number of tie point increases when the flying altitude increases.

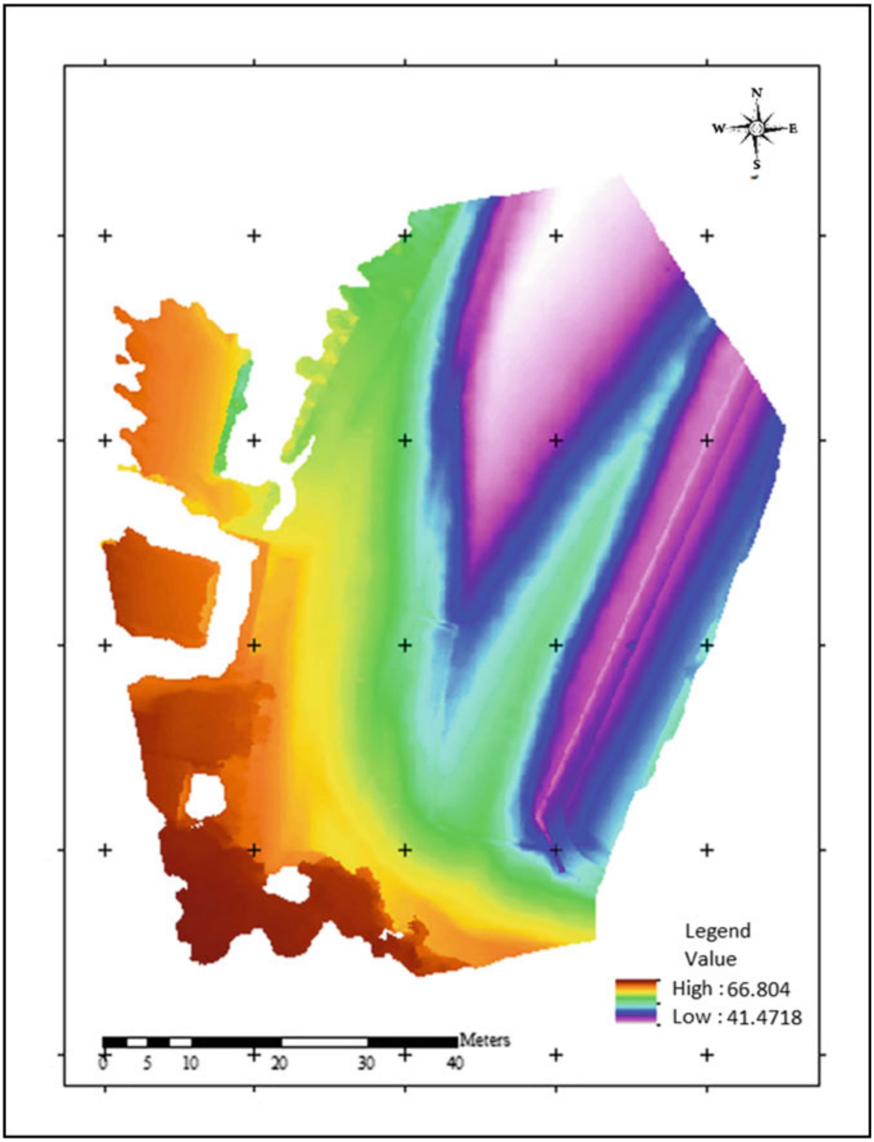


Fig. 14 DEM for flying altitude of 40 m

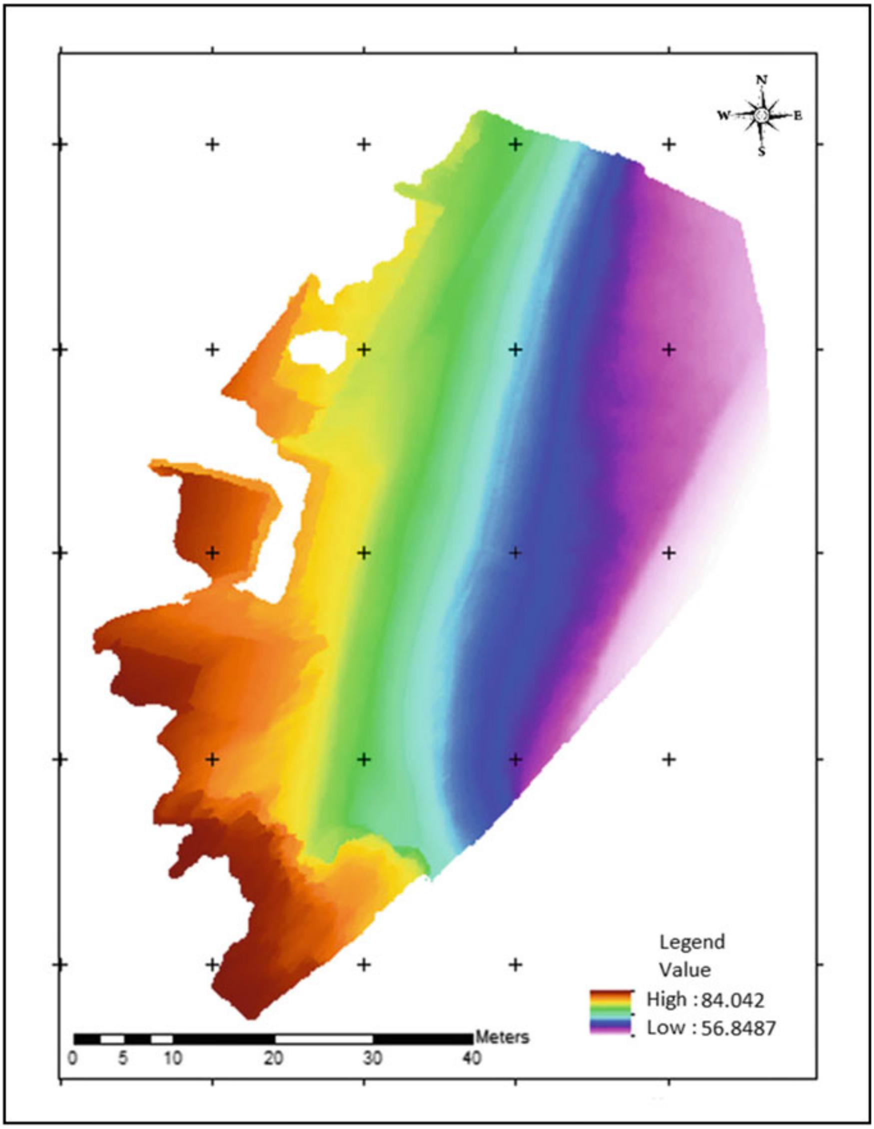
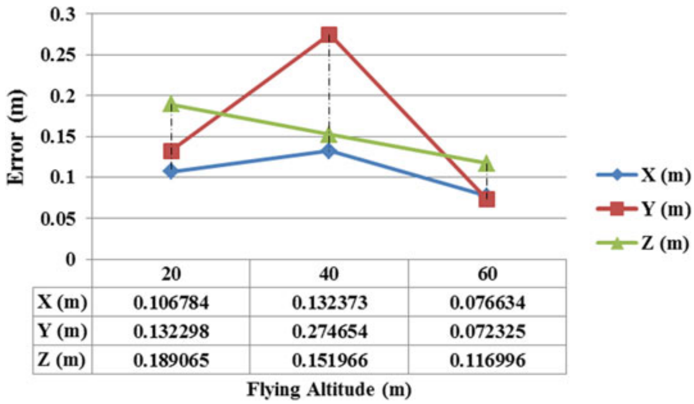


Fig. 15 DEM for flying altitude of 60 m



	20	40	60
X (m)	0.106784	0.132373	0.076634
Y (m)	0.132298	0.274654	0.072325
Z (m)	0.189065	0.151966	0.116996

Fig. 16 Error at different flying altitudes

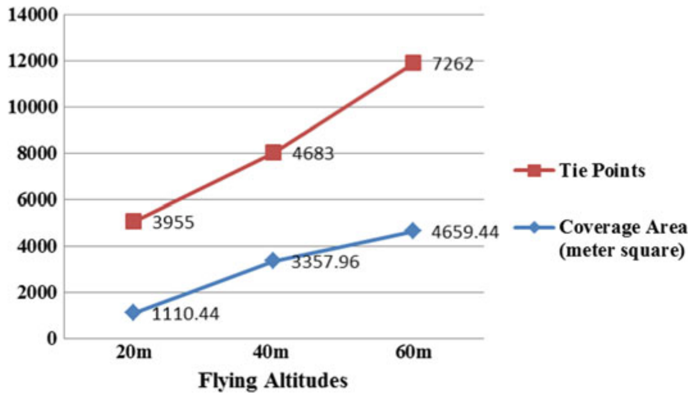


Fig. 17 Numbers of tie points and coverage area at three different altitudes

14 Conclusion

As conclusion, this study has successfully evaluated the orthophoto and DEM accuracy based on different flying altitudes using UAV technology to produce slope map. It also demonstrates the capability of UAV technology to fly at three different altitudes over the study area. Three different flying altitudes were performed, namely 20, 40, and 60 m. Throughout the study investigation, the overall error of X, Y and Z value at different altitudes for the study area are at centimeter level.

Different flying altitudes have influence on the error of X, Y and Z which means the higher the altitudes, the smaller will be the error of coordinates obtained. In addition, the analysis showed that the coverage of slope area and number of tie point increases when the flying altitude increases. Subsequently, this practical study contributed to the slope work activities where the specific requirements for flying altitudes have been clearly stated. It is recommended in future studies will expand the analysis using UAV attached with multi sensor such as LiDAR, thermal camera, and infrared to capture slope data.

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