ASSESSMENT OF UAV BASED LOW COST PHOTOGRAMMETRIC SYSTEM FOR AERIAL MAPPING

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ABSTRACT: Use of Unmanned Aerial Vehicles (UAVs) in surveying and aerial mapping revolutionized the approach of remote sensing and popularized the use of drones for various mapping applications. The basic procedure in producing an accurate map from UAV imagery consist of three steps which are, establishing ground control points mainly using GNSS method, perform the aerial survey and process the survey data with a suitable photogrammetric software. The three main components of a photogrammetric system, UAV, GNSS system and image processing software are the key cost factors influencing the overall feasibility of its application for a given task. In the case of survey grade components, the system would add up to a very high cost making it only viable for large scale projects which would justify their expenditure.

In this study, the focus is on adopting consumer grade photogrammetric system components to achieve a considerable level of accuracy and precision and assess its applicability thereby justifying the feasibility upon both cost and accuracy parameters. The UAV used for the study is a DJI Phantom 3 Professional while Ublox Neo M8P as the GNSS unit and OpenDroneMap as the image processing software which is an open source software available for free. The accuracy and limitations of such a system is analyzed considering the benefits to the community as an affordable complete mapping solution.

KEY WORDS: UAV, Photogrammetry, GNSS

1 INTRODUCTION

The evolution of aerial platforms for aerial photogrammetry has taken great leaps starting from pigeons with cameras tied on its body to the now existing high tech drones during the past few decades. The invention of consumer grade UAVs created an exponential growth on the field of aerial photography and revolutionized its capabilities which paved way to new applications and inventions starting from the basics of photogrammetry (Kakaes et al., 2015). This resulted in greater accuracy in photogrammetric end products and expanded its applicability to be used in other sub streams of mapping in both 2D and 3D domains with many advantages.

Although drones were initially made for military purposes, with advancement in drone's maneuverability, flight time, and size, researchers soon exploited these features to carry out different tasks (Kakaes et al., 2015) like photography, filmography, delivery systems, surveillance, remote monitoring and many other. Many studies carried out in the application of drones as aerial photogrammetric platforms has resulted in the use of drones for collecting photogrammetric and LIDAR data. The use of UAVs have replaced other conventional aerial photogrammetric platforms like balloons and aero planes due to their superior applicability as mapping platforms.

In the study, the aerial survey or photographic data collection was carried out using a DJI Phantom 3 Professional drone which is a consumer grade drone available in the market. Even though the intended purposes of a consumer grade UAVs are applications such as photography and videography, it is proven that these UAVs can provide a reliable platform as a photogrammetric tool at a low cost compared to expensive survey grade UAVs. A decent consumer grade UAV under 1500USD comes with built in GPS and reliable flight controller which enables executing autonomous flight plans and with a good camera or ability to mount one. With these features a consumer grade UAV can become a powerful mapping tool.

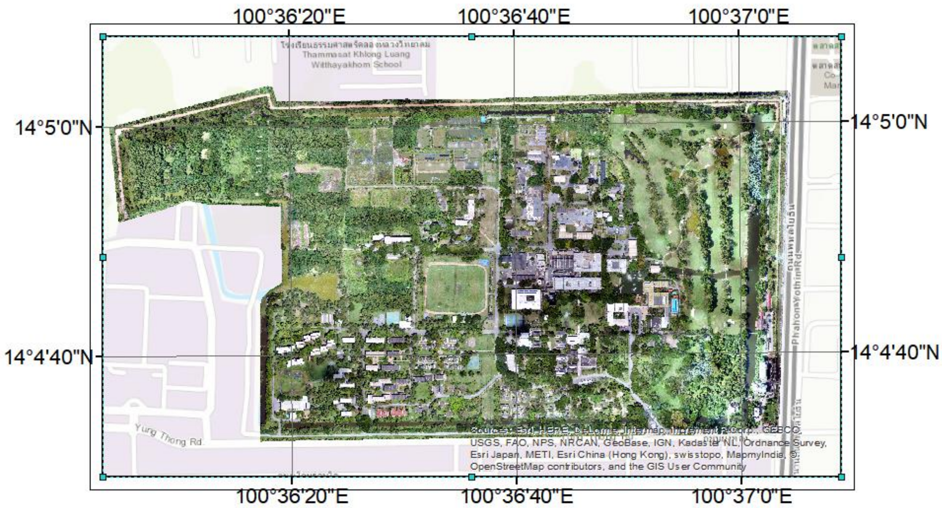
The second component in the process of making an aerial map which is the establishment of GCPs using a GNSS method is the most crucial element which determines the final accuracy and precision of the output. The technological advancements and availability of GNSS (GPS/GLONASS/QZSS) have introduced very precise location data with no cost involved. Survey grade mapping systems use multi-channel high precision GNSS receivers for ground control measurement. However, the starting price of such a survey grade GNSS receiver will be around 2000USD such as Piksi GNSS receiver and the prices will go up with more accuracy. In the study, ublox GNSS receiver was used for the purpose of establishing GCPs with a centimeter level manufacturer defined accuracy under good observation conditions which cost only150USD.

The third and final step of processing collected aerial photographs for the generation of an aerial map was carried out using OpendDroneMap (ODM) which is an open source software freely available (Park, Jeong, Kim, & Choi, 2016). The photogrammetric processing of UAV imagery to map products like orthoimages and DSMs is a mathematically complex process which incorporate digital image processing methods and today's computer vision algorithms. Software like Agisoft Photoscan and Pix4D handle this processing in a user friendly environment and provide high accurate results and yet comes with very high price. The performance of ODM compared with existing commercial software was evaluated.

2 STUDY AREA AND EQUIPMENT

2.1 Study Area

Study Area: Asian Institute of Technology, Khlong Luang District, Pathum Thani, Thailand



The study area contains all the general cases and challenges to a mapping project such as low clearance and poor accessibility which makes it a perfect study area to analyze a complete mapping solution.

Figure 1: Study Area: AIT, Thailand

2.2 Equipment Used

UAV: DJI Phantom 3 Professional

DJI Phantom 3 is a consumer grade UAV specialized for videography with a fairly good flight time and a 4K camera. Although DJI Phantom 3 is not a drone specialized for mapping, with the integration of a powerful flight planning application like DJI GS Pro, this consumer grade drone can be re modelled into a decent quality mapping drone. With the ability to customize flight parameters like flying altitude, side overlap and capturing mode etc, DJI Phantom 3 Professional can be easily converted into a mapping drone at a low cost.

Table 1: Specifications of DJI Phantom 3 Pro

Type	Quadcopter
Weight	1280g
Camera	Sony EXMOR 4K RGB 12MPix
Max Flight Time	Approx. 23 minutes
Maximum speed	16m/s
Maximum flying height	300m AGL(mapping)
Price	USD 999 (discontinued)

GNSS Receivers: 1. u-blox NEO M8P high precision GNSS module with patch antenna
2. Emlid Reach (u-blox NEO M8T) with patch antenna
3. Trimble NetR9 with geodetic antenna

Table 2: Specifications of GNSS receivers

	u-blox NEO M8P 	u-blox NEO M8T 	Trimble NetR9 
Tracking	GPS, GLONASS, QZSS	GPS/QZSS, GLONASS, BeiDou, SBAS, WAAS, EGNOS, MSAS, GAGAN, Galileo	GPS/QZSS, GLONASS, BeiDou, SBAS, WAAS, EGNOS, MSAS, GAGAN, Galileo, OmniSTAR
No of channels	72	72	440
Update Rate	Up to 10 Hz	up to 4 Hz	50Hz
Accuracy	Standalone = 2.5 m RTK = 0.025 m + 1 ppm	2.5 m	Horizontal: 8 mm + 1 ppm Vertical: 15 mm + 1 ppm
Convergence time	RTK < 60 sec	-	<10 seconds
Price	150 USD	Emlid Reach - 235 USD U-blox NEO M8T - 30.49 USD	N/A

Total Station: Topcon GPT 70005i

Measurement accuracy: non Prism mode = +/- 5mm | Prism mode = +/- (2mm + 2ppm measured dist.)

Software and Libraries

a) Pix4D mapper
b) OpenDroneMap (ODM)
c) Agisoft Photo Scanner
d) RTKLib 2.4.3
e) u-center by u-blox
f) DJI GS Pro

3 PHOTOGRAMMETRIC GROUND CONTROL ESTABLISHMENT

Ground Control Points are points on the ground with their known coordinates (horizontal position and altitude) in the spatial reference system. Obtaining accurate spatial coordinates of GCPs is a vital step in the process of obtaining accurate orthophotos and DSMs. The coordinates of GCPs are usually obtained through tachymetry or most commonly by a GNSS measurement. Inclusion of GCPs will result in higher levels of accuracy in the final product as they are used in camera calibration in addition to georeferencing final map products (Agisoft, 2014). DJI Phantom 3 Professional drone has its own GPS system and therefore geotags all the photos taken from its camera which can be processed using mapping software to obtain orthomosaics and DSMs without GCPs. The horizontal accuracy of the phantom 3's map products without GCP is found to be 1.75 m in a previous study (Madawalagama, Munasinghe, Dampegama, & Samarakoon, n.d.). However the accuracy parameters of the final products obtained with the inclusion of GCPs in the processing step will be very high.

In the study, 15 points spread around the area of study were used as GCPs with known spatial coordinates. These 15 points were chosen after analyzing their suitability as GCPs for a GNSS measurement to obtain their spatial coordinates with highest possible accuracy with good observation conditions for the GNSS receivers. Conditions like an elevation mask of >15 degrees and a good clearance was considered in choosing these 15 points for GCPs.

Furthermore, three categories of distinct features were used to identify points as GCPs.

Category 1 - Existing distinct features already available on the ground.
Category 2 - Painted cross on the ground with a template
Category 3 - Painted cross on a feature board with specific dimensions

Priority was given to choose category 1 and 2 as much as possible and avoid category 3 since the probability of errors in displacement of a category 3 GCP point is greater than that of category 1 and 2 while the survey was ongoing. Dimensions of GCPs are designed considering ground sampling distance so that it is possible to mark the GCPs on the images in sub pixel accuracy. It was possible to identify the exact center of GCPs in most of the images, even though there is an unavoidable blurring due to UAV movement and rolling shutter effect of the camera.

When it comes to accuracy of the ground control of a UAV survey, precision of the measurements should be highly considered. Applying a good GCP set with good distribution and high accuracy can raise the accuracy of a map product to centimeter level. But if the GCPs are low in accuracy and precision, they will reduce the final accuracy of the model and even distort the model completely so that it can no longer be processed. The reason is that GCPs are also used to optimize the camera's internal parameters in modern photogrammetric software so a bad set of GCPs will do more harm than good. An accuracy test of the proposed low cost receivers was carried out in order to make sure that these devices are capable enough to match with the requirements of UAV mapping.

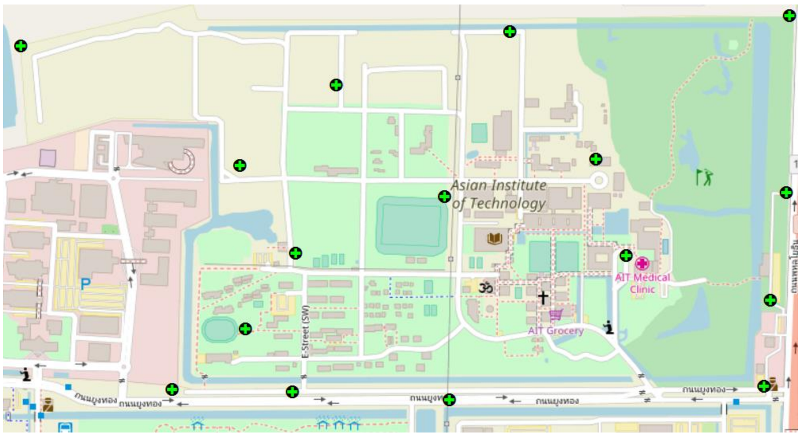


Figure 2: GCP distribution

(a) (b) (c) (d)

Figure 3: GCP markers (a) Marker dimensions (b) Category 1 (c) Category 2 (d) Category 3

3.1 Accuracy Validation of Low Cost GNSS Receivers

Assessment of accuracy obtained for spatial coordinates using low cost GNSS receiver is a major objective in the study since the accuracy and limitations of the complete system will be highly influenced by the GNSS component in the complete low cost mapping solution suggested in the study. The goal of this task is to establish and validate a methodology to use the low cost GNSS receivers in UAV ground control establishment.

As every GNSS system is subjected to several sources of measurement errors (Hedgecock, Maroti, Sallai, Volgyesi, & Ledeczi, 2013)**,** it is important to understand the limitations to reduce the possible errors. The following issues can be stated as factors that affect the accuracy of GNSS and the following steps were taken to minimize the influence from such erroneous factors.

Issue	Precaution
Ionospheric effect	• Use improved differential GNSS method
Errors of satellite orbit	• Use precise ephemeris data from IGS instead of the navigation data transmitted by the satellites
Multipath errors	• Use a ground plane • Choose the GCPs with a low multipath environment

The above precautions were taken in the experiment in order to achieve the maximum possible and practical accuracy of the GNSS receivers. The processing of GNSS data is done by Post Processing Kinematic (PPK) method which is similar to Differential GNSS (DGNSS) method except that carrier phase measurements are taken into account to increase the accuracy as the both receivers are able to provide raw measurement data with carrier phase and pseudorange. In Post processed kinematic (PPK) method, mobile GNSS receiver (Rover) records positioning data which can be adjusted using corrections from a stationary GNSS reference receiver (Base) after the data has been collected.

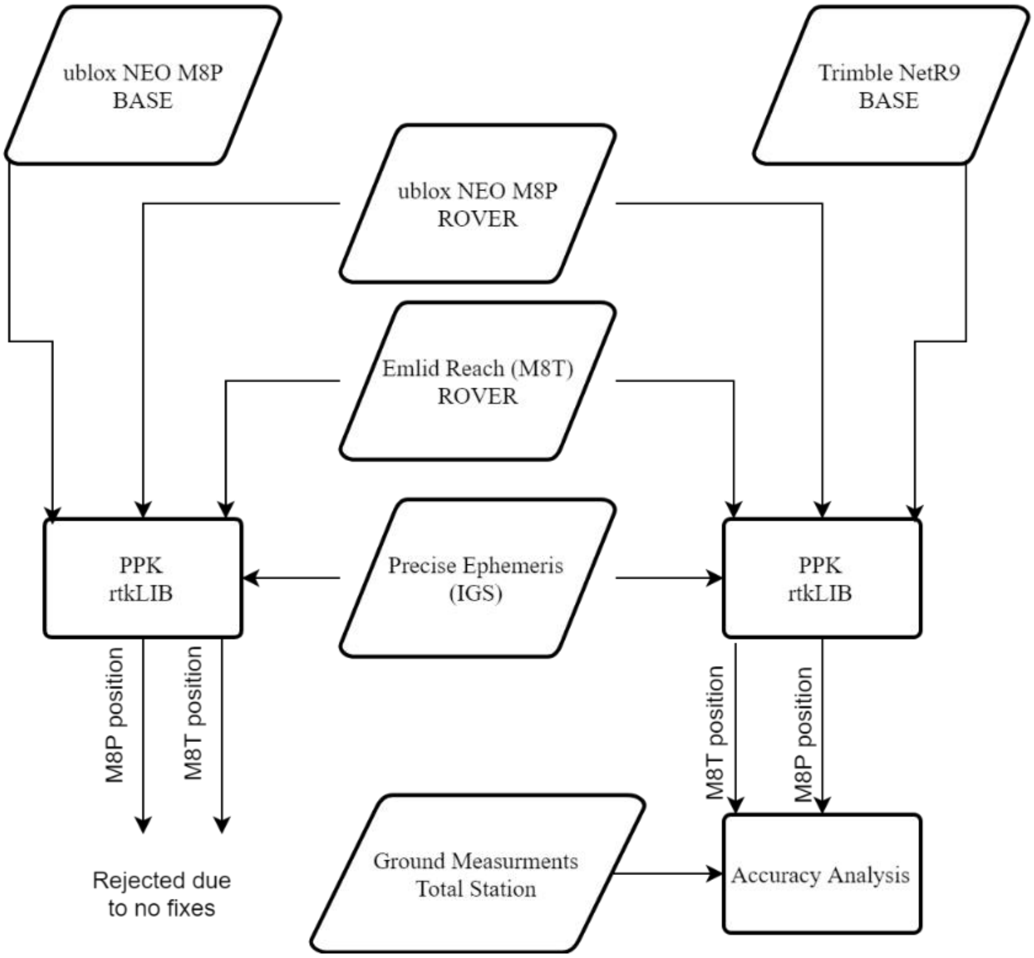
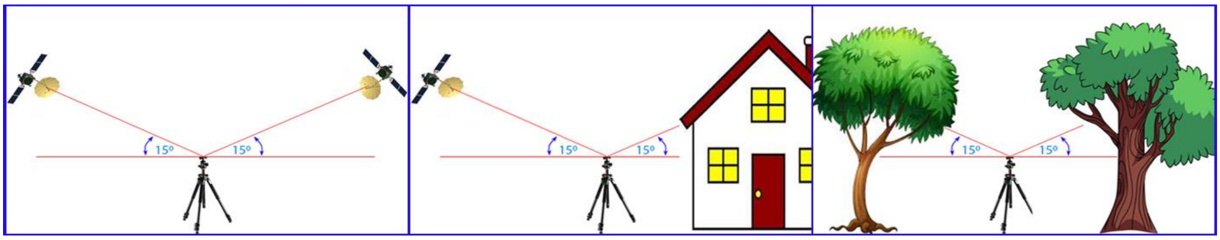


Figure 4: Accuracy assessment procedure

3.2 Experiment Environment

As an accuracy assessment for u-blox M8P and emlid Reach GNSS receivers, 3 scenarios were observed and measured using a total station with reference to a known reference point.

Case 1 - Favorable conditions for good GNSS observations with high clearance.
Case 2 - Location with low multipath errors.
Case 3 - Extreme worst conditions with very poor clearance.



Case 1 Case 2 Case 3

Figure 5: Experimental scenarios

Two GNSS base stations were set up, a high end survey grade Trimble NetR9 receiver with a geodetic GNSS antenna and a low cost u-blox M8P receiver with a patch antenna.

3.3 Analysis and Results

Each point is observed with both u-blox M8P receiver and emlid Reach receiver for 15mins at one station. Both base stations were set up prior to the rovers. To get the ground truth measurements, total station survey was carried out and measurements from GNSS receiver were compared later.

When computing the results with M8P as the base station, it was unable to obtain a significant number of ambiguity fixes so that almost every solution was a float. The analysis with the M8P as a base was not performed due to this reason.

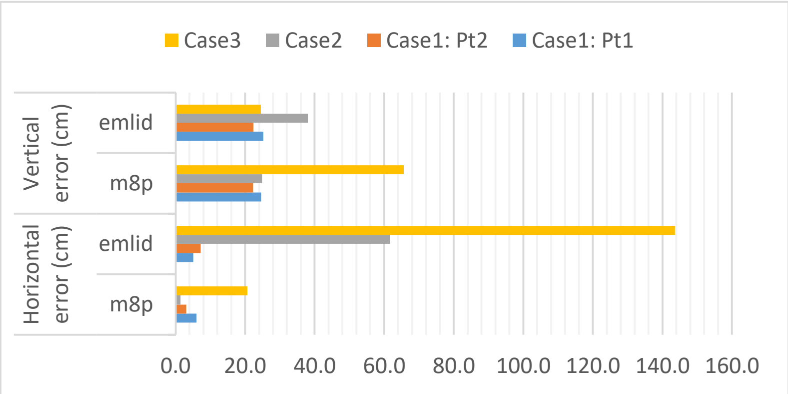
Table 3: u-blox NEO M8P analysis with Trimble NetR9 as the base

Scenario	Horizontal error (cm)	Vertical error (cm)	Average no. of satellites	no. of observations	Ambiguity Fixes	Time to first fix (s)	For fixed solutions		
							Stdv. of easting (cm)	Stdv. of northing (cm)	Stdv. of height (cm)
Case1: Pt1	3.1	22.3	8	1337	90%	0	0.1	0.1	0.8
Case1: Pt2	1.4	24.9	6	910	56%	0	1.7	1.7	5.5
Case2	6	24.6	9	728	20%	551	0	0.1	0.1
Case3	20.6	65.6	5	897	7%	0	74.9	87.1	217.2

Table 4: Emlid Reach (u-blox NEO M8T) analysis with Trimble NetR9 as the base

Scenario	Horizontal error (cm)	Vertical error (cm)	Average no. of satellites	Total no. of observations	Ambiguity Fixes	Time to first fix (s)	For fixed solutions		
							Stdv. of easting (cm)	Stdv. of northing (cm)	Stdv. of height (cm)
Case1: Pt1	5.1	25.2	8	6924	68%	128	0	0.1	0.4
Case1: Pt2	7.2	22.4	6	3310	87%	20	0.7	1.1	3.8
Case2	61.7	38	8	3536	18%	129	38.3	15.9	84.6
Case3	143.6	24.5	5	4094	10%	25	49.3	72.6	268.8

Figure 6: Accuracy comparison of M8P and M8T receivers



The results show a remarkable centimeter level accuracy and precision in favorable situations (Case 1) and reduced in multipath environments (Case 2). The positional accuracy of both rovers drops to unacceptable levels in high multipath environments (Case 3). When comparing the two rovers, u-blox M8P receiver shows superior performance in every scenario compared to the M8T.

4 MEASURING SPATIAL COORDINATES OF GCPS

As a rule of thumb the accuracy of the ground control should be better than the marking accuracy. In this study, GCPs are designed so that it can be marked within sub-pixel accuracy. According to the GCP design and the ground sampling distance, the expected accuracy should be more than 8 cm in horizontal. It was validated that M8P rover with a survey grade GNSS unit can provide such accuracy and reliability in good observation conditions. GCPs are chosen only with good observation conditions and surveyed with previously verified methodology. The data was observed with u-blox M8P as the rover, Trimble NetR9 as the base station and processed using PPK method with rtklib software. The average observation time is 30 mins for each station which gained 81% of average fixes.

5 FLIGHT PLANNING AND DATA COLLECTION

The area of study was covered in 6 missions using DJI GS Pro flight planning application. Observations done during 1000h to 1400h to achieve a uniform ground illumination and a minimum of shadows. A sum of 1532 photographs were collected in covering the whole study area.

Table 5: Flight Parameters

Flying height	: 100m AGL	Forward overlap	: 80%	Side overlap : 75%
Maximum speed	: 10 m/s	Maximum flight time	: 20 mins	

6 PHOTOGRAMMETRIC PROCESSING TO ORTHOMOSAIC AND DSM

Conceptual photogrammetry which involves taking measurements from photographs, is actually a complex mathematical process. It can be stated as the inversion of photography as the camera captures 3D space into a two dimensional photograph. The task of photogrammetry is to bring back the 3D world from the 2D images. The accurate map products such as orthomap or DSM which are undistorted and uniform in scale, can then be produced from the virtually reconstructed 3D world.

Processing of UAV imagery into accurate map products and models is based on a classical photogrammetric model, which is enhanced in turn by a powerful computer vision algorithm (Wolf & Dewitt, 2000). This enables the automatic extraction of numerous key points in the images and optimises camera parameters such as external orientation and camera model.In general, the three main steps involved are, Initial Processing, Point Cloud and Mesh Generation and finally, DSM Orthophoto Extraction.

The processing of UAV imagery in this project was done using 3 different softwares, Pix4D Mapper, Agisoft PhotoScan Professional and OpenDroneMap. Pix4D Mapper and Agisoft PhotoScan are reputed commercial softwares for UAV mapping which provides accurate results both geometrically and radiometrically. Processing with Pix4D and Agisoft PhotoScan softwares is highly automated and requires minimum manual interaction. OpenDroneMap (ODM) is a free and open source software for processing UAV imagery into map products which runs in command line interface. During the processing of Photoscan and Pix4D, 8 out of 15 GCPs are used as 3D points for georeferencing the products and refining the model parameters, and 7 points are used as checkpoints to validate the geolocation accuracy.

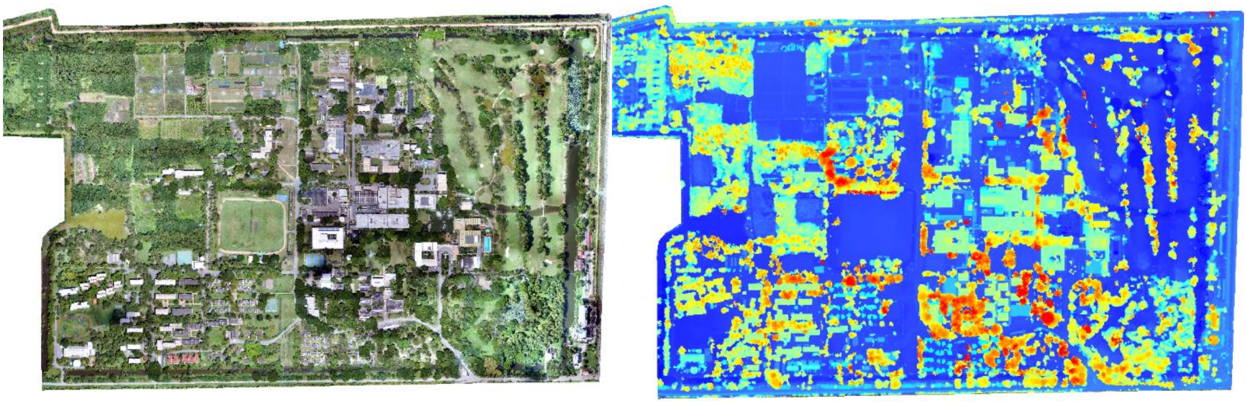


Figure 7: Orthoimage (left) and DSM (right) of the study

7 ANALYSIS OF MAP PRODUCTS

The results of 3D mapping with both Agisoft PhotoScan and Pix4D, achieved a good sub-meter level of accuracy by processing with the GCPs which fulfils most of the aerial mapping requirements. The slight difference of the accuracies in both software can be due to the marking accuracy as well as the difference of software’s internal algorithms.

Table 6: Error statistics of map products

		Agisoft PhotoScan	Pix4D	ODM
Geolocation Accuracy	Planimetric (XY) (cm)	27	28.5	N/A
	Height (Z) (cm)	27	40.1	
	Total (cm)	38.2	49.2	
Mean Reprojection Error (px)		1.27	0.263	

When analyzing the quality of the orthomap, both Agisoft Photoscan and Pix4D gives remarkable results with no distortions which can be visually identified. It can be visually interpreted that camera’s inherant distortions and relief displacement is successfully removed by the software. However unsolved distortions can be seen in the ODM map product. Due to a system error, it was unable to process ODM with GCPs. The orthoimage and DSM from ODM without GCPs are visually acceptable in most of the areas.

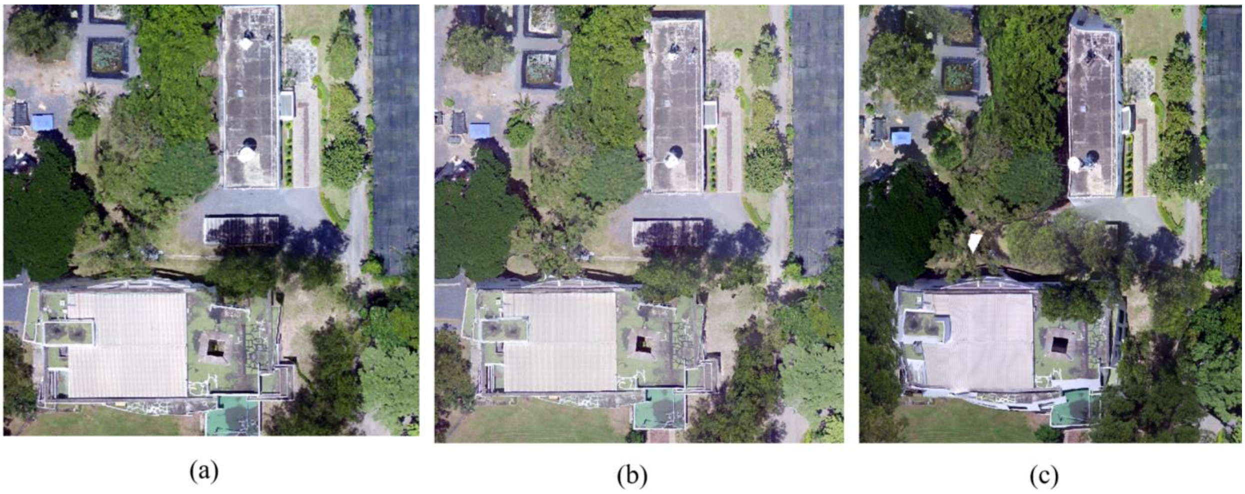


Figure 8: Comparison of orthoimages (a) Pix4D (b) Agisoft Photoscan (c) ODM

8 DISCUSSION

Use of survey grade UAVs for mapping has taken over conventional surveying methods involving a lot of labour and time during the past decade. However, the feasibility of adopting such a survey grade UAV for mapping can incur a lot of capital expenditure which make them only viable for large scale projects which justify their expenses. Therefore, even at present, many of minor scale projects where mapping with a considerably low capital expenses use conventional survey methods such as total stations and theodolites. As the existing technology has provided solutions already for a foolproof method of using UAVs for mapping, the major concern among geomatics researchers and UAV enthusiasts is to focus on providing a complete mapping solution with low cost and considerable accuracy for civilian work.

There are significant advantages of UAV mapping. When compared to the traditional areal mapping, the price of a Cessna 172 airplane which is commonly used for acquiring aerial photographs will cost around 300 000 USD. Satellite imagery such as worldview 3 provide map products to 31 cm resolution but is unable to provide 3D maps in such resolution. A commercial survey grade drone like senseFly’s eBee RTK which would cost around 25 000 USD. If a consumer grade drone such as DJI Phantom 3 Professional can be used which cost around 1000 USD to achieve the same purpose of mapping, the major component of cost factors in a mapping system can be brought down by 25 folds. The study proves that a consumer grade UAV and today's’ GNSS receivers can provide a low cost solution for UAV based mapping.

Nowadays, GNSS is the method most commonly used in photogrammetric ground control. Compared to the other conventional surveying methods, survey grade GNSS units provide excellent accuracy and precision with less amount of time spent in the field. Survey grade GNSS receivers use multi-frequency / multi-constellation choke-ring antennas because they have excellent multipath mitigation properties which is critical in providing the best performance (Beran, Langley, Bisnath, & Serrano, 2005). These survey grade GNSS units comes with a very high price tag as the accuracy is highly dependent on the build quality of the antenna and receiver as well as the approach to solve the position in the receiver. In survey grade mapping, Dual channel GNSS are used to set GCPs and therefore the accuracy can be enhanced but during this study, single channel GNSS receivers were used to establish its compatibility for mapping to a satisfactory level of accuracy. But it is essential to understand the accuracy limitations and limiting factors of such receivers to be applied in a mapping task with reliability.

Finally the survey grade mapping packages come up with photogrammetric software to bring the 2D images back to 3D world. Such image processing softwares have to be purchased additionally in order to create orthomosaics and DSMs from collected aerial photos which would cost around 3 500 USD for one year subscription. However, this additional cost incurred in processing the drone images can be saved by using an open source software like OpenDroneMap in a linux platform which is available for free. OpenDroneMap does not include a graphical user interface (GUI) and therefore the manipulation of the software is difficult and it makes it more difficult as there is very little documentation. However the contributors to the ODM software are improving it continuously and it is a work in progress.

Table 7: Analysis of capital expenses for UAV based mapping

	UAV	**GNSS receiver**	**Image Processing Software**	**Total cost**
Survey grade mapping solution	eBee by sensefly 10 000 USD	2 x PRECIS-BX306 GNSS RTK by TERSUS with dual band antenna 3 400 USD	Pix4D Mapper/ Agisoft Photoscan 1 year subsc. 3500 USD	16900 USD
	Sensefly eBee RTK 25000USD			28500 USD
Recommended low cost mapping solution	DJI Phantom 3 Professional 1 000 USD	U-blox NEO M8P GNSS + PRECIS-BX306 GNSS RTK by TERSUS with dual band antenna 1850 USD	Pix4D Mapper/ Agisoft Photoscan 1 year subsc. 3500 USD	6350 USD
In near future	DJI Phantom 4 or newer: ~1500 USD	U-blox NEO M8P GNSS + PRECIS-BX306 GNSS RTK by TERSUS with dual band antenna 1850 USD	Open Drone Map Free	3350 USD

9 CONCLUSION

This study represents an assessment of a low cost mapping solution using consumer grade UAVs and low cost GNSS receivers with its suitability for different real world scenarios and limitations. The study was able to provide results to establish that the DJI Phantom 3 Professional drone can be used as a powerful mapping drone along with flight planning applications like DJI GS Pro. The low cost GNSS receiver u-blox NEO M8P also provided proof of cm level accuracies for ground control data which justify their applicability for accurate mapping applications. However, the use of OpenDroneMap for producing orthomaps should be further analyzed to refine the accuracy level as that of Pix4D Mapper and Agisoft PhotoScanner while the open source software continues to develop in future.

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