Research Article

Multicopter UAV-Based Photogrammetric Mapping for Road Design

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Unmanned Aerial Vehicles (UAVs) can be used for close range mapping. In engineering survey works, the conventional survey involves huge cost, labour, and time. Low-cost UAVs are very practical in providing reliable information for many applications such as road design. UAVs can provide the output that meets the accuracy of engineering surveys and policies, especially for small-scale mapping. UAVs are also a competitive technology which is stable and rapidly developing, same as other surveying technologies. This study investigates the performance of multicopter UAV for road design. This study involves four phases which consist of preliminary study, data collection, data processing, and analysis. This study focuses on the UAV as a tool to capture data of the ground from a certain altitude. The analysis includes UAV flight planning, image acquisition, and accuracy assessment of road design. It can be concluded that UAVs can be used to provide data for road design with reliable accuracy.

1. Introduction

Developed countries are constantly faced with high maintenance cost of aging transportation highways. The growth of the motor vehicle industry and accompanying economic growth has generated a demand for safer, better performing, less congested highways [1]. The growth of commerce, educational institutions, housing, and defense has largely drawn from government budgets in the past, making the financing of public highways a challenge. The multipurpose characteristics of highways, economic environment, and the advances in highway pricing technology are constantly changing. Therefore, the approaches to highway financing, management, and maintenance are constantly changing as well. Management of safety is a systematic process that strives to reduce the occurrence and severity of traffic accidents. The man/machine interaction with road traffic systems is unstable and poses a challenge to highway safety management [2]. High accuracy of topographical information and features information are very important in good road alignment design [3]. There are many previous methods used to capture topography information such as manned satellite

imagery, radar, LiDAR, and land survey. The Ground Sampling Distance (GSD) is the most important characteristic to be considered during road design. The other information such as elevation and positioning also influences the road design.

Previously, topography information especially in road design was obtained from land survey using total station. The land survey method required a lot of time to complete the survey especially for large area. Therefore, this method also increased the cost of the project and labour used to complete the project. The land survey method totally relies on human resource in order to carry out road design. Therefore, the road design is prone to the systematic error done by human. The undulated area is a challenge for land survey method because it requires the human to climb up and down and access the challenging site on their own. The other factor is weather conditions and land ownership issue during conducting the land survey. The long road alignment might cause a lot of errors and it might have problem to merge the data at the end [4]. The other method used to capture topography information is Light Detection and Ranging (LiDAR). This method offers the accurate topographic data

for road design application. LiDAR method can cover the large area in a minutes and could provide the accurate data. LiDAR is also an active sensor which is capable of capturing data the day or night. However, this method is very expensive which can affect the total project cost. Satellite imagery also can be used to obtain topographic information for road design application. The satellite imageries were captured from thousand kilometres from the earth surface [5]. This method could provide the location and classification of topographic information. This method also has its own problem due to the revisit time of the satellite at the same location, weather condition which refer to cloudy condition, and resolution of the satellite images.

The key for increasing the safety of highway systems is to design, build, and maintain them to be far more tolerant of the average range of this man or machine interaction with highways. Technological advancements in highway engineering have improved the design, construction, and maintenance methods used over the years. These advancements have allowed for newer highway safety innovations. By ensuring that all situations and opportunities are identified, considered, and implemented as appropriate, they can be evaluated in every phase of highway planning, design, construction, maintenance, and operation to increase the safety of our highway systems.

The new technology such as UAV photogrammetry opens numerous applications in the close range domain, combining aerial and terrestrial photogrammetry but also introduces low-cost alternatives to the conventional manned aerial photogrammetry [6–9]. UAV systems also offer various applications other than mapping such as surveillance, archeological, geohazard studies, monitoring, and fire disaster [10–22]. The UAV system is equipped with various intelligent sensors such as barometer, Inertial Navigation System (INS), Global Positioning System (GPS), flight control, navigation control, sonar, and infrared and Electronic Speed Controller (ESC) [23–27]. There are many kinds of UAVs available in the market which are affordable. UAV photogrammetry describes photogrammetric measurement platforms which operate as either remotely controlled, semiautonomously, or autonomously. The definition covers balloons, kites, gliders, airships, rotary, and fixed wing UAVs with the capability for photogrammetric data acquisition in manual, semiautomated, and automated flight modes [28]. Model helicopters are able to operate closer to the object and are highly flexible in navigation compared to fixed wing UAVs. Microdrones are more stable against environmental conditions such as wind. The developments of model helicopters and comparable autonomous vehicles are primarily driven by the artificial intelligence. Nowadays, close range areas can be mapped by combining aerial and terrestrial photogrammetry using UAV technologies and also as an alternative way for large area mapping [29]. Low cost UAVs are used in mapping projects with low budgets. However, in the previous years, low-cost UAVs have reached a level of practical reliability and professionalism which allow the use of these systems such as mapping platforms. In study, the multirotor UAV is used to capture the topographic information for road design application.

2. Methodology

This study involves four phases which include preliminary study and planning, data collection, data processing, results, and analysis. The methodology plays an important role in implementing this study accordingly. The first phase is on the preliminary study and the planning of the work which are crucial parts of the study that require a lot of reading and planning. The first phase also includes reconnaissance, calibration of the equipment, and measurement of data. The next phase is on data collection using UAV images and getting the detailed plans from the unit facilities of UiTM Puncak Alam. Then, both sets of data are processed in the laboratory for the third phase of this study which is data processing. The UAV images are processed using the UAV Agisoft PhotoScan software which can generate the X, Y, and Z coordinates of the proposed road. This phase also includes the construction of road mapping of the area of interest. After the data processing is completed, the results are analysed. The flowchart of the research methodology is shown in Figure 1.

Reconnaissance survey is a general study of an area of interest that might be used for a road or airfield. The reconnaissance survey report should summarise all the collected information, including a description of the site, a conclusion on the economy of its use, and, wherever possible, maps. For UAV surveys, the important thing is the area of coverage of the site. Furthermore, the reconnaissance must include geographical features for the decision-making of minimum flying height, direction of flight path, and type of UAV used. Other than that, this survey also needs to consider the wind direction to make sure that it is carried out smoothly and also for the direction of the flying path to obtain better image capture. Figure 2 shows the location of study. Camera calibration is carried out before acquiring the digital aerial images or aerial photographs for the purpose of recovering all camera parameters for digital image processing. This study used a 4K camera with 4000 x 3000 resolution and the process of camera calibration also gives a result of focal length, principal points, radial lens distortion, and tangential lens distortions. These camera parameters need to be included during the interior orientation step in digital image processing.

The UAV used in this study is the Quad-Rotors, Phantom 3 Professional. The UAV weight (including battery and propellers) is about 1280 g and the diagonal size (excluding propellers) is 350 mm. Its maximum speed can achieve 16 m/s (ATTI mode, no wind) and has a GPS Mode that uses GLONASS satellite. The UAV maximum flight time is approximately about 23 minutes. A single person can operate this UAV to collect the image data. The hardware uses IOS Ipad to control the flight planning and a computer for processing. The detailed plan is acquired from the unit facilities in the DWG file in AutoCAD and it can be georeferenced using the ArcGIS software. After that, the acquired UAV images were processed using the Agisoft PhotoScan software. Next, the outputs are transferred to the AutoCAD and the ArcGIS software to analyse the outputs.

2.1. Data Acquisition and Flight Planning. Flight planning involves the control of dimension of the study area, number

FIGURE 1: Research methodology.

FIGURE 2: Location of study area.

FIGURE 3: Flight planning for acquisition of data.

of strips required, pixel size, photo scale flying height, and percentage of the end lap and side lap. The Map Pilot used is a friendly software for the drone, module Waypoint Editor, and it is able to design flight planning. There are about 122 number of images with 148 m flying height created in the flight planning. In general, the aerial photographs should be overlapped at least 80% and the side for at least 60%. This requirement needs to be fulfilled to make sure that quality photogrammetry results could be obtained. The customised parameters such as spatial resolution, altitude,

endlap, sidelap, and wind direction are as shown in Figure 3. After parameters setting of the flight planning is completed in the Map Pilot, the flight planning is uploaded to the UAV. After uploading, the start button is pressed to begin the image acquisition. Once it started, the UAV gave information of the current altitude of the mission. After the UAV entered the survey area, images are automatically captured every 2.5 seconds and identical speed is used to ensure accurate data. Once the mapping is completed, the UAV returned to the takeoff location and landed automatically.

TABLE 1: Coordinates of road design.

CPs	Conventional Road Design			UAV Images road Design		
	X (m)	Y (m)	Z(m)	X (m)	Y (m)	Z(m)
CP1	-26926.806	3109.908	42.124	-26926.435	3110.456	41.431
CP2	-26847.403	3128.347	44.154	-26847.554	3128.184	44.310
CP3	-26715.708	3158.090	39.246	-26716.024	3157.619	38.570
CP4	-26813.002	3178.296	41.423	-26813.127	3178.034	41.133
CP5	-27024.207	3186.877	43.806	-27024.254	3186.939	44.205
CP6	-26967.798	3240.365	43.403	-26967.768	3240.422	43.903
CP7	-27064.443	3216.702	43.206	-27064.472	3216.801	43.322
CP8	-27167.600	3078.530	44.500	-27167.648	3078.670	44.406
CP9	-27188.670	2957.179	44.720	-27188.601	2957.334	45.069
CP10	-27182.072	2969.390	44.407	-27181.878	2969.580	45.146
CP11	-27078.698	2825.722	48.370	-27078.685	2825.727	48.610
CP12	-26879.317	2724.228	48.912	-26879.289	2724.209	48.114
CP13	-26860.444	2769.504	49.188	-26860.493	2769.433	48.635
CP14	-26851.342	2876.084	45.039	-26851.430	2875.994	44.772

FIGURE 4: Location of GCPs and CPs.

2.2. Preprocessing and Processing. The ground control points (GCPs) and check points (CPs) are collected using GPS observation through the rapid static technique. This technique can determine the position information which includes Northing, Easting, and Elevation (X, Y, and Z) through postprocessing by using the GNSS Solution software. This software can convert the raw data to a Rinex file, where it can be used in any GPS processing software for adjustments. The rapid static technique only takes 5 to 20 minutes for observation. In this study, there are six GCPs established for absolute orientation and fourteen CPs. For a better view, Figure 4 shows all the locations of the GCPs and CPs.

After data acquisition has been completed using the multirotor UAV, all acquired raw images data and GCPs are processed using the Agisoft PhotoScan software. The results are presented in the form of a digital map or hardcopy. The Agisoft PhotoScan software requires camera information such as pixel size, focal length, radial lens distortion, and tangential distortion to carry out the interior orientation. A total of six GCPs have been established during absolute orientation. After adding the raw images data in the Agisoft PhotoScan software, the process will start with aligning the photo input in a high accuracy setting and using the Reference for Pair Preselection. The key and tie point limit are 40,000 and 20,000. After aligning the photos, a reference to

establish the GCP on the UAV images is selected by importing the coordinates in the (txt) file. The coordinate is illustrated by point features in the software, where it needs to move the point to the exact location of the GCP. The process will produce Orthophoto and a map.

2.3. Data Analysis and Assessment. The objective of this study is to assess the accuracy of road mapping from the UAV product. There are two assessments describing the point and visual analysis. For quantitative accuracy, the error difference between the coordinates of check points by GPS (rapid static technique) and UAV processed images data is assessed using RMSE. After the accuracy assessment has been conducted, an alternative road can be designed using the UAV data and ground survey mapping of the study area. The designed road is focused on increasing the efficiency of road flow. The optimal road alignment is determined based on topographic map of the area and mapping the existing road network. There are two types of alignments which are vertical and horizontal alignment. The horizontal and vertical alignments based on topographic features from the UAV data are determined.

3. Results and Analysis

The analysis of the accuracy of the road mapping, production of the road map and all the results will be analysed in this chapter, including the evaluation of UAV images for road design or alternative road. All calculations are made for the RMSE point accuracy assessments and the road design. The accuracy is analysed based on computation of the RMSE between the coordinates of 3D stereo model and the check points. The locations of the check points are shown in Figure 4 with 14 samples (Table 1). It shows the comparisons between CPs using GPS and the 3D coordinates of the stereo model in Agisoft Photoscan software.

It can be seen that the accuracy could be achieved using the UAV system. The smaller the value of the RMSE

FIGURE 5: Digitized features from UAV images.

FIGURE 6: Digital surface models of UAV images data.

calculated, the higher the accuracy. Hence, the accuracy of the orthophoto can be calculated by the RMSE value. The latitude, longitude, and elevation (X, Y, and Z) are processed using the GNSS Solution software where the raw data collected from the site are converted to (Rinex) file to be used in any GPS processing software for adjustments. After processing the raw data of the UAV images in the Agisoft Photoscan software, the outcome of orthomosaic in a (tif) file will be imported to the Global Mapper software in order to carry out the digitisation of the features as shown in Figure 5. The analyses are carried out based on road features and the elevation produced by the Digital Surface Model (DSM) (Figure 6). The digitised features are displayed in ArcGIS to visualise the difference from the AutoCAD drawing.

After both road designs are completed, both UAV images and conventional road design are compared with the coordinate of chainage in every 30 meter intervals. In the CDS software, parameters of the road are needed to design the road curve such as bearing in, bearing out, and the optimum radius for the road curve. Two road curves have been designed with the radius of 50 and 60 meters for the first and second curve. After clicking the position of the Intersection Point and keying in the value of radius, bearing in and bearing out the software will calculate the other parameters values which are available for the designed road curve such as arc, chord, and tangent length. Figure 7 shows the finished road design

FIGURE 7: Complete road designs for UAV Images and Conventional Survey.

with 50 and 60 m radius. This radius follows the public work department standards for Exclusive Motorcycle Lane, EML.

4. Discussions

After producing the adjustment coordinates, the WGS84 coordinate system is converted to a local coordinate system from angular units to meters. The coordinate system that is chosen is Cassini Malaysia, Selangor, by using Kertau as a datum. The reason that the coordinate system is converted to Cassini Malaysia is because it is easy to analyse the meter units than the angular degree minutes and seconds, where it can check the miss-closure (meter) of the data. The RMSE for x, y, and z coordinates are ± 0.155 metres, ± 0.228 metres, and ± 0.479 metres, respectively (Table 2).

In the Global Mapper software, digitising of features are carried out using orthophoto image and then exported to ArcGIS in order to produce a map. The analysis only focused on road features and it could be displayed in ArcGIS to visualise the differences between UAV road mapping and conventional road mapping. The AutoCAD drawings are obtained from the unit facilities of UiTM Puncak Alam. Figure 8 shows the slight difference between two methods of producing the map; the road with the pink outline is drawn using the AutoCAD software which is obtained from conventional ground measurement while the grey outline is digitised from the UAV's orthophoto in the Global Mapper software.

5. Conclusions and Recommendations

Road mapping is produced from the UAV images using the Agisoft Photoscan software to create an orthophoto image. All the images went through the scaling and level process which also referred to the orientations such as interior, relative, and exterior orientation. It is demonstrated that the UAV together with the digital camera are capable of acquiring aerial photograph successfully for large scale mapping in a short amount of time. This study shows that UAV is also capable of producing road mapping at the selected study area. All of the results are analysed using the Root Mean

TABLE 2: Analysis on disparity between conventional and UAV coordinates.

CPs	X(m)	Y(m)	Z(m)	X ² (m)	Y ² (m)	Z ² (m)
CP1	-0.371	-0.548	-0.693	0.138	0.300	0.480
CP2	0.151	0.163	-0.156	0.023	0.027	0.024
CP3	0.316	0.471	0.676	0.100	0.222	0.457
CP4	0.125	0.262	0.290	0.016	0.069	0.084
CP5	0.047	-0.062	-0.399	0.002	0.004	0.159
CP6	-0.030	-0.057	-0.500	0.001	0.003	0.250
CP7	0.029	-0.099	-0.116	0.001	0.010	0.013
CP8	0.048	-0.140	0.094	0.002	0.020	0.009
CP9	-0.069	-0.155	-0.349	0.005	0.024	0.122
CP10	-0.194	-0.190	-0.739	0.038	0.036	0.546
CP11	-0.013	-0.005	-0.240	0.000	0.000	0.058
CP12	-0.028	0.019	0.798	0.001	0.000	0.637
CP13	0.049	0.071	0.553	0.002	0.005	0.306
CP14	0.088	0.090	0.267	0.008	0.008	0.071
RMSE (m)				0.155	0.228	0.479

FIGURE 8: Visual Accuracy Assessments of Both Road Designs.

Square Error (RMSE). RMSE can assess the accuracy of the UAV images using the check points that have been measured on the ground for data validation analysis. The designed road in this study is for proposing an alternative road to increase the efficiency of road traffic flow. The Digital Terrain Model (DTM) data from the UAV images processed is used to evaluate the geographic features where it must follow the design policy parameters in order to help control the design of the road. The safety of the users must also be calculated by selecting the super elevation of the proposed road. Therefore, the alternative road can be designed using the parameters for road design provided by public work department standards. In the future, the accuracy of the orthophoto can be improved and enhanced by increasing the number of GCPs and CPs during data collection in the field using the GPS technique. It can also minimise the RMSE in data processing. The use of DTM (digital terrain model) for road design to check the accuracy of the road designed and to improve the validation of using UAV for road design construction. Different types of UAV should be used to improve the flexibility of the survey works; for example, a fixed wing UAV can cover a large area to

get more details for the topographical map to design a road. Different methods of camera calibration could be applied to optimise the quality of the UAV image processing. MyRTKnet data should be used as a base for better control of the coordinate GCP to apply on the UAV images for processing. Different flying heights should be applied for UAV to conduct better results for road design.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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