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UAV Photogrammetry for Road Defects Mapping

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***Abstract* –** Road defect detection is essential to road maintenance to prevent traffic accidents. In Malaysia, road conditions are one of the leading causes of road accidents that may cause fatalities and injuries. In Malaysia, between 2010 and 2019, the number of road accidents increased from 414,421 cases in 2010 to 567,516 cases in 2019. Unmanned Aerial Vehicles (UAV) are helpful instruments that may be utilised to obtain accurate data for road defect mapping. The purposes of this study are (i) to investigate road distress using low-altitude photogrammetry by generating orthophoto from low-altitude UAV photogrammetry in detecting road defects and (ii) to assess the accuracy of road defects from orthophoto and 3D model point clouds. The benefits of utilising UAVs include high flexibility, low cost, easy manoeuvrability and minimal field work. The results of this study show that orthophoto is very suitable for classifying road defects. Furthermore, the rise in road defects is caused by congested roads near construction and industrial regions, with many trucks passing through the study area. The results demonstrate that the large crack area can be successfully analysed using 3D point clouds, but a narrower crack with roughness features is complicated and challenging to be spotted.

Keywords – *Road defects, UAV, Orthophoto, Point clouds*

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1. Introduction

Aerial photogrammetry captures and displays the Earth's surface using aerial photographs. Unmanned Aerial Vehicles (UAV) photogrammetry has applications in many fields, such as environment (Darwin et al., 2019), traffic monitoring (Butila and Boboc, 2022), archaeology (Themistocleous, 2020) and forensic (Sazaly and Ariff, 2022). The use of UAVs for surveying purposes is more beneficial because UAVs are more ambitious because they require less time for information gathering and lower expenses compared with the utilisation of old-style aircraft (Martinez-Carricondo et al., 2018). According to Zulkipli and Tahar (2018), UAVs can be utilised for close-range mapping. UAVs can capture aerial data using downward-facing sensors, such as RGB or multispectral cameras, and create output that meets the precision requirements of engineering surveys and policy, particularly for small-scale mapping.

Road accident is a global tragedy with an ever-rising trend. In Malaysia, road condition is one of the leading causes of road accidents that may cause fatalities and injuries. According to the number of road accidents in Malaysia between 2010 and 2019, the number of instances increased from 414,421 cases in 2010 to 567,516 cases in 2019 (Kementerian Pengangkutan Malaysia, 2022). Road distress is "any sign of poor or unfavourable pavement performance or signs of imminent failure; any unsatisfactory performance of a pavement short of failure".

The state of the pavement is a major issue for the Malaysian roads and highways sectors. Due to roadway deterioration, developed nations have lost infrastructure worth billions of Ringgit in Malaysia. They will lose billions more if they do not take fast action to protect their highways. In 2019, a budget of RM 2 billion was allocated for new road building, replacement, rehabilitation, and maintenance.

The most cost-effective strategy to save Malaysia's highways is maintaining good roads. Road information must be regularly revised and measured to address maintenance issues like cracking. Road administrators need more details on the road network and its surroundings for several reasons, including urban planning and road network management (Darko and Prusa, 2014). The conventional method to analyse the pavement condition data was collected by human inspectors who travelled along roads assessing the deterioration and compiling reports. This approach is time-consuming, expensive, and dangerous.

To address these issues, the high spatial resolution technique be employed to discover the map defects detection through low altitude photogrammetry. Our goal is for UAVs to be able to detect road defects. According to Tahar and Ahmad (2012), UAV is a competitive technology that is stable and rapidly improving, similar to other surveying technologies. This research uses a UAV to collect road condition data for the two epochs. Thus, UAVs may offer reliable road mapping accuracy, providing low-altitude imagery in detecting road defects (Abd Mukti and Tahar, 2021).

2. Materials and Methods

There are several phases involved in this study. The main parts explained in more detail are the preparation stage, data collection using UAV, Ground Control Point (GCP) and Check Point (CP) establishment, processing images by Pix4D software and analysing of road defects. Pix4D is the top UAV photogrammetry software, created for users who wish to create 3D maps and point clouds from data captured during a drone flight. It will automatically convert drone, hand, or plane images and deliver exact, georeferenced 2D maps and 3D models. They are adaptable, timely, and compatible with various applications and software.

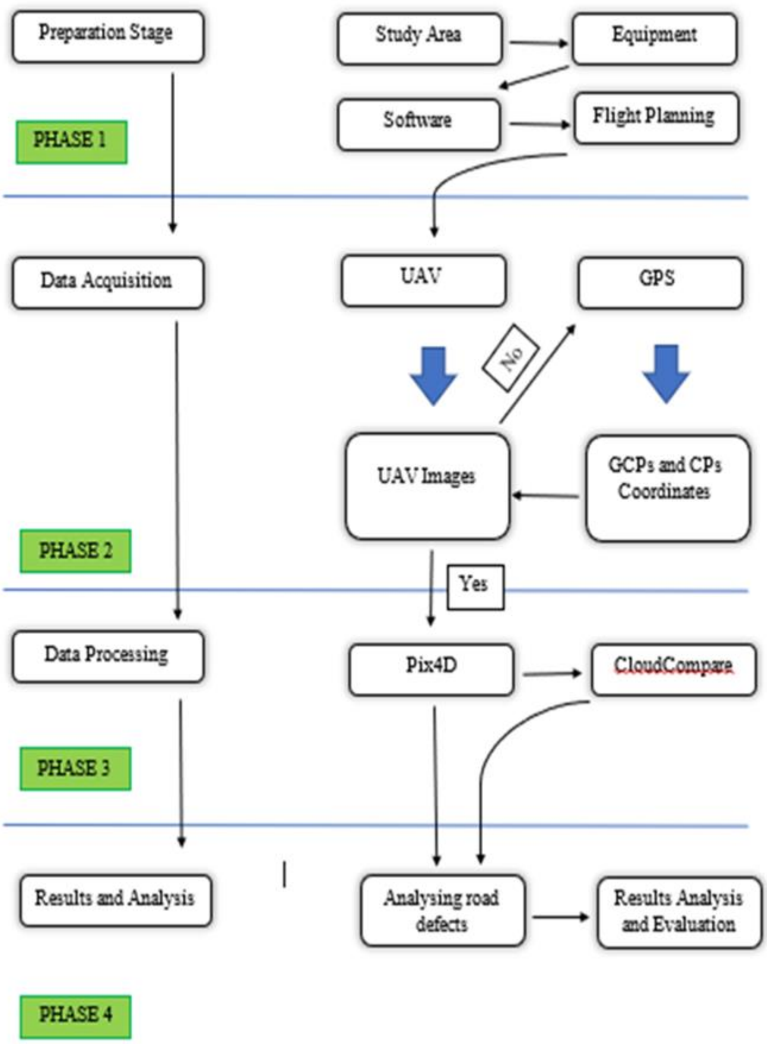

Figure 1. Research methodology flowchart

2.1 Phase 1: Preparation Stage

This stage focuses on the purpose of the study. Several aspects must be considered, such as the preparation of the flight planning and the instrument used. To capture the UAV image, elements like photographic scale, flying height of the UAV and coverage should be determined. The place to take off and land the UAV must be an open area for easy in controlling the UAV. The UAV image also must be well organised for smoothing in data processing and analysis. Other things that need to be considered before the observation are instruments installed on the UAV, such as cameras, batteries and other UAV components.

2.1.1 Study Area

The study area occurred in Taman Industri Alam Jaya, Puncak Alam, Selangor. The area of study is 1 Hectare. Two roads are involved in data collection: Jalan Bukit Cerakah and Jalan Taj 1. The total distance of the road involved in the data collection activity is 500 m. This area was chosen as a study area because it is close to industrial and construction areas with a large number of heavy vehicles passing by, which is one of the factors that cause road damage. Figure 2 shows the study area.

Figure 2. Study area

2.1.2 Equipment and Software

To get the data, specific equipment is used. For the Global Positioning System (GPS) observation, Spectra Precision SP80 is used to establish Ground Control Point. WingtraOne Gen 2 was used to capture the aerial photograph of the Taman Industri Alam Jaya. Two software used in this study is Pix4D and CloudCompare. Pix4d is used to generate orthophoto and point clouds, while CloudCompare is used to analyse point cloud data from Epoch 1 and Epoch 2. Table 1 shows the specification of the camera (WingtraOne Gen 2).

Table 1. Specification of WingtraOne Gen 2 camera

Sensor type	Full frame
Sensor size	35.9 mm X 24 mm
Megapixel	42 MP
Shutter type	Leaf shutter
Focal length	35 mm

2.1.3 Flight Planning

Flight planning is important in the planning phase; determining how many per cent of end lap and side lap is also essential. Generally, the end lap is 60%, and the side lap is 30% for each pair of images (Tahar, 2012).

Figure 3. WingtraPilot interface

2.2 Phase 2: Data Acquisition

An autonomous flight mission has been applied to capture images in the study area. UAVs fly according to the flight line designed by the operator. WingtraOne Gen 2 is used in this study. Two data collections were made as part of this investigation on November 13th and December 12th to track any road damage that happened. The one-month period between these flights is to monitor road damage to get the difference between the data. Table 2 and Table 3 show the flight information for Epoch 1 and Epoch 2.

Table 2. Flight information for November 13th (Epoch 1)

No.	Aspect	Detail
1.	Coverage area of imaging	1 hectare
2.	Flight period	5 minutes
3.	Altitude (m)	80 m
4.	Total no. of photos taken	244

Table 3. Flight information for December 12th (Epoch 2)

No.	Aspect	Detail
1.	Coverage area of imaging	1 hectare
2.	Flight period	7 minutes
3.	Altitude (m)	80 m
4.	Total no. of photos taken	390

2.2.1 Ground Control Point and Control Point Establishment

GCP and CP are established before the data acquisition using UAV. In this study, the fast-static GPS method was used in the selected point of GCP, and the real-time kinematic GPS method for the chosen point CP. The data obtained was in three-dimensional coordinates in GDM 2000/Selangor Grid. Figure 4 shows the observation of GCP using Spectra Precision SP80.

Figure 4. Observations of GCP

2.3 Phase 3: Data processing

Data processing is important to process the data. In this study, Pix4d is used to process the orthophoto obtained from the UAV image captured at the study area. Besides, CloudCompare is used to study and analyse the point clouds of the two datasets.

2.3.1 Pix4D

Pix4D is the leading UAV photogrammetry software, specifically designed for users who want to make 3D maps and point clouds from data captured during a drone flight. It will automatically convert images taken by drone, hand, or plane and deliver highly precise, georeferenced 2D maps and 3D models. Pix4D have three main processing steps: initial processing, point cloud and mesh, and the last step is DSM, orthophoto, and index.

Step 1: Initial Processing

Firstly, the images were exported into the software. A batch of photos is downloaded into Pix4D. Since the photos are already georeferenced based on the flight log data, the default geolocated image coordinate system has been used.

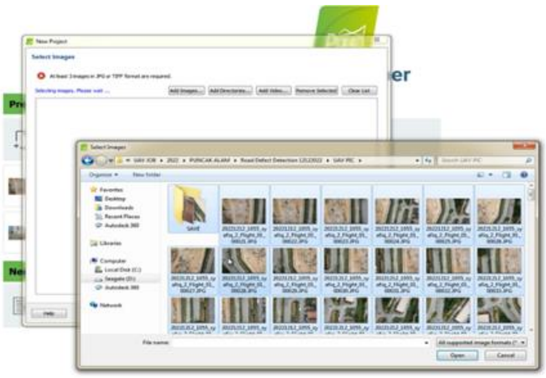

Figure 5: Pix4D’s interface for uploading images

Steps 2 & 3: Point Cloud and Mesh & DSM, Orthophoto, and Index

The points cloud, mesh, and texture are processed in the points cloud and mesh phases. The purpose is to calculate the depth information for each image, represent the model area and equalise object texture for the model. The significant parameters set in this phase are Image Scale, Point Density and Minimum Number of Matches. It used the high-quality setting in Image Scale, and five image matches in re-projected. The triangulated irregular network form was interpolated to generate the mesh. The DSM is generated from the dense, representing the terrain and object surface model to produce an orthophoto. Figure 6 shows the point clouds and mesh in the processing part.

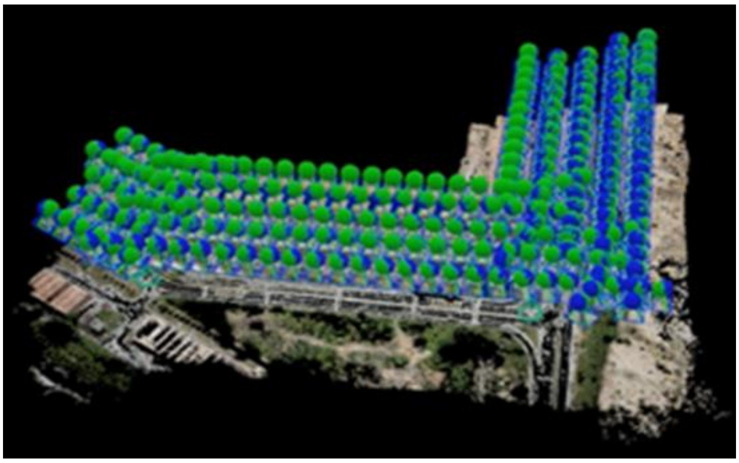

Figure 6: Point cloud and mesh

2.3.2 CloudCompare

The point clouds data generated from Pix4D was uploaded into the CloudCompare software. Both point cloud data from Epoch 1 and Epoch 2 have been set in the same coordinate system. After that, the point clouds were identified and trimmed into several parts of road defects. The point clouds from Epoch 1 and Epoch 2 were merged, then the distances from clouds to clouds were calculated. Figures 7, 8 and 9 show the processing part.

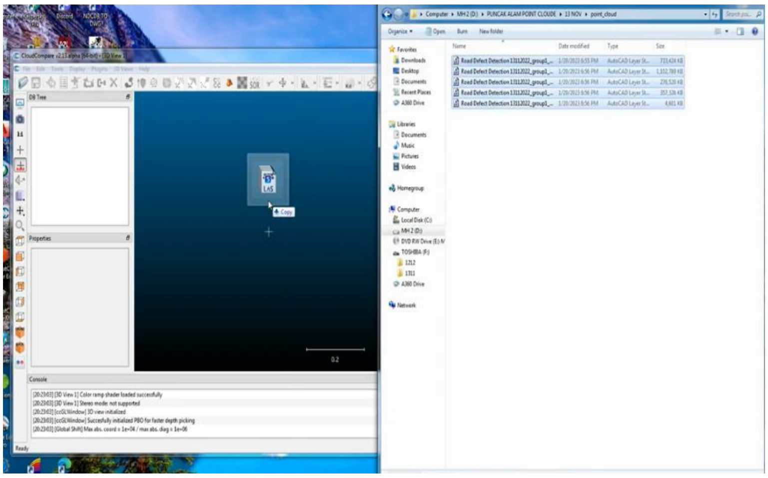

Figure 7. Uploading point clouds

Figure 8. Trimmed 3D point clouds

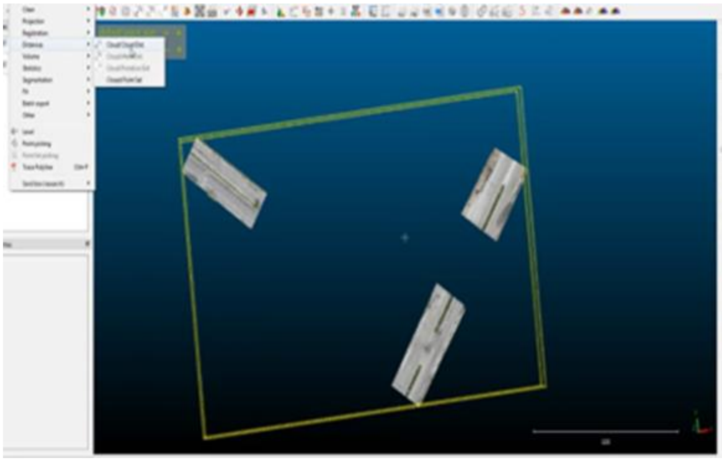

Figure 9. Compute distances from clouds to clouds

3. Result and Analysis

This section discussed the results after the measurement and data processing work described in the previous chapter. It includes analysis and results obtained from UAV image processing using Pix4D software. This section is important in listing the results as evidence of the objectives of this study being achieved.

3.1 Result of Orthophoto

Orthophoto is one of the results of processing aerial images. Orthophoto provides 2D coordinates for the x and y axes. Figure 10 shows the orthophoto generated from the aerial image acquired in Epoch 1, while Figure 11 shows the orthophoto generated from the aerial image acquired in Epoch 2.

Figure 10. Orthophoto for Epoch 1

Figure 11. Orthophoto for Epoch 2

3.2 Analysis

The data was analysed to determine the capabilities of UAVs for the classification analysis of road defects. In this study, the results were examined and analysed to create an orthophoto to classify road defects.

Road defects classification found in orthophoto Epoch 1 and Epoch 2 are rutting, potholes, patch failures and ravelling. There is no difference in the classification of road defects in Epoch 1 and Epoch 2, which are one month gap of monitoring. However, there are increasing potholes and patch failures in Epoch 2. Figures 12, 13 and 14 show the classification of road defects.

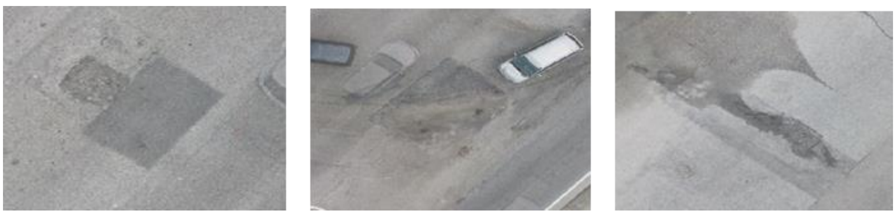

Figure 12. Patch failures in both epoch

Figure 13. Ravelling and potholes in both epoch

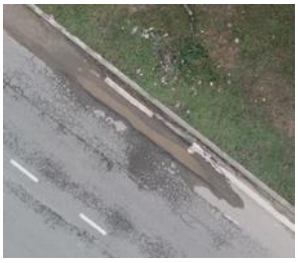

Figure 14. Rutting in both epoch

3.2.1 Analysis of Measurement Road Defects

After the classification of road defects was executed, orthophoto was measured to collect the lengths and widths of distress regions. Due to the uneven road distresses, length and width were not precisely defined. Therefore, the length and width data only functioned as a reference to give a rough idea of the size of the road distress. Figure 15 shows the measurement of road defects using an orthophoto.

Figure 15. Measurements of road defects using orthophoto in Epoch 1 and Epoch 2. Measurements marked in the orthophoto represent magenta lines are the length, and blue lines mark the width.

Table 4: The corresponding comparison measurement data

No	Epoch 1			Epoch 2			Area Difference (m²)
	Length (m)	Width (m)	Area (m^2)	Length (m)	Width (m)	Area (m^2)	
1	5.116	1.310	6.702	5.486	1.310	7.187	+ 0.485
2	1.789	0.390	0.697	1.789	0.390	0.697	0.000
3	5.499	4.394	24.163	5.499	4.777	26.269	+ 2.106
4	2.657	1.872	4.974	2.958	1.872	5.537	+ 0.563
5	8.053	2.298	18.506	8.053	2.298	18.506	0.000
6	10.873	2.429	26.411	10.873	2.429	26.411	0.000

As the results above demonstrate, there is an area difference between Epoch 1 and Epoch 2 refer to table 4 above (No. 1, 3, and 4), but no change in some road defects (No 2, 5, and 6). The increase in road defects is due to the congested roads, close to construction and industrial areas, with many trucks passing by in the study area.

3.2.2 Comparison of Road Defects Point Clouds

Two datasets of 3D point cloud models obtained with Pix4D software were analysed with the help of CloudCompare. Several toolbars in CloudCompare can be used to register the cloud, align and show the cloud-to-cloud distances, also obtaining a colour scalar field as a result of the difference analysis. Figure 16 shows the effect of cloud-to-cloud distance between Epoch 1 and Epoch 2.

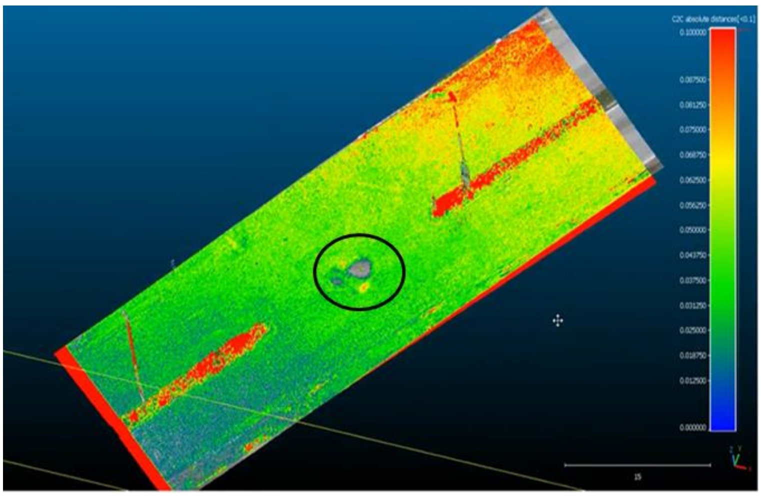

Figure 16. Results of the cloud-to-cloud distance between Epoch 1 and Epoch 2. The black circle in the results above represent the cavity of the road defects

The parameters of cloud-to-cloud distance are < 0.1m (10cm). The colours in the RGB scale of the 3D point clouds model show the deviation between the points of Epoch 1 and Epoch 2. The cavity of road defect shown in the black circle in Figure 16 represents 0.0187m (1.87cm) depth. Not all road defects detected using orthophoto can be analysed using CloudCompare because some road defects have roughness features such as potholes, pile-ups such as patch failures, and water in the cavity, which causes the point clouds produced to be imperfect.

4. Conclusion

The study aims to examine road distress utilising low-altitude photogrammetry. The findings from the study are used to discuss starting from data processing until the analysis of 3D point clouds between Epoch 1 and Epoch 2.

The first objective of this study is to produce an orthophoto from low-altitude UAV photogrammetry to detect road defects. In this study, photogrammetric products such as orthophoto are successfully produced using Pix4D software using images captured by UAV.

The second objective of this study is to evaluate the accuracy of the 2D model of road defects from orthophoto and 3D model point clouds. This objective is successfully achieved. The road defects classification was done using the 2D model of orthophoto, and the 3D model of point clouds was used to analyse the point clouds of the two data epochs.

Based on the analysis of measurement road defects between Epoch 1 and Epoch 2, the increase in road defects is due to the congested roads, close to construction and industrial areas, with many trucks passing by in the study area. The comparison of road defects points clouds between Epoch 1 and Epoch 2 shows the cavity of road defects represents 0.0187m (1.87cm) depth.

In this study, UAV has successfully examined road distress utilising low-altitude photogrammetry. This study employs the high spatial resolution technique to discover map defects detection through low-altitude photogrammetry. This method can help map and classify road defects to prevent road accidents in Malaysia and help Jabatan Kerja Raya (JKR), Local Authority, and Highway Concession Company provide information and produce a map.

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