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Unmanned Aerial Vehicle Technology Use in Visual Road Inspection at Ft005, Johor Bahru-Melaka

Masiri Kaamin[1*], Saiful Azhar Ahmad Tajudin[2], Nor Athirah Basri[2], Rosdi Ab Rahman[1], Ahmad Hakimi Mat Nor[1], Muhammad Azraie Abdul Kadir[1], Mardiha Mokhtar[1] and Pingping Luo[3]

[1]Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Kampus Pagoh, Johor, Malaysia
[2]Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
[3]School of Water and Environment, Chang'an University, Xi'an, China

ABSTRACT

Visual road inspection is one of the key phases of road maintenance to examine and describe the condition of road infrastructure. The local authority still uses the conventional road inspection method. However, this method has its drawbacks. In this study, Unmanned Aerial Vehicle (UAV) was used to help in the road infrastructure information search and to determine the severity level of the road in visual road inspection. The objectives of this study are: to capture road images at study locations using UAV technology, to produce data for pavement distress using the UAV photogrammetry method, and to analyse the level of pavement distress using the Pavement Condition Index (PCI) method. Results from this study showed that UAVs are suitable for aerial mapping with the condition that a professional operator operates it during data acquisition and the use of UAVs as a verification medium is more efficient than the conventional method because it measures every end and vertex of the road using a digitising method, whereas the conventional method measures from vertex to the vertex of the road using a theodolite. A total of 206 locations with 11 different types of pavement distress have been identified by the PCI results using this technology. Overall, the pavement distress of the road from Sections 1 to 4 is at a serious level and necessitates reconstruction.

Keywords: Visual road inspection, UAV technology, photogrammetry method, Pavement Condition Index (PCI)

1. INTRODUCTION

Malaysia is moving to become a developed country. Roads play an important role in helping the growth of the economy and society in Malaysia. Presently, roads in Malaysia, including Sabah and Sarawak, are classified into three primary classes that have more than 17,830 (km) federal roads, state roads 61,100 (km) and toll expressway 1,700 (km) [1]. In Malaysia, the Public Works Department of Malaysia (JKR) was given responsibility for routine, periodic, and urgent maintenance. Road maintenance work needs to be undertaken to ensure safety and comfort for users and make traffic more effective. Maintenance management requires an assessment of the pavement condition to be carried out periodically to ensure the traffic is still smooth without disruption on the surface of the pavement. Road maintenance includes two phases, known as maintenance and rehabilitation (M&R). Before maintenance work was carried out, visual road inspection is the first work to be undertaken to evaluate the structural condition of pavement distress [2].

*masiri@uthm.edu.my

For many year, the local authority in Malaysia still used a manual walking survey to collect data on road conditions. Traditionally, pavement distress surveys are carried out manually through human observation, interpretation, and effort. The manual walking survey method was used to inspect the road pavement while walking and collecting data on a data sheet. Visual surveys are a common method used by most engineers; however, they have significant drawbacks such as being slow in progress because they can only collect a small amount of data per day, expensive because more workers are required to conduct these surveys, and the data collected through manual walking surveys tend to be more subjective and less accurate because it is influenced by evaluators' experience [3]. It also has high repeatability because the assessment of a given pavement section may differ from one survey to the next, posing a serious safety hazard to surveyors due to high speed and volume traffic. Alternatively, a UAV use study was conducted to identify the location and type of road damage more easily, quickly and safe. The latest methods of using UAV technology is a significant increase in quality and performance compared to the manual walking. In addition, the use of the UAV in road inspections also help planners in the planning process to estimate cost and time road maintenance. It is also beneficial by using new technology to remove the competition from using costly machinery such as High-Speed Data Acquisition for visual road inspection works.

As a new technology, UAV is used in this study to determine quality and performance compared to the manual walking survey to detect damage in the road surface. UAV promises rapid data acquisition for analysis, especially for small aerial mapping with high-resolution imagery. High-resolution images captured by the UAV platform are capable of extracting metric information from the Earth's surface [4]. UAVs are technologies that can be used in various fields such as agriculture, surveillance, geographic mapping, road maintenance and disaster management [5]. The objectives of this study are; (i) to capture road images at study locations using UAV technology, (ii) to produce data for pavement distress using the UAV photogrammetry method, and (iii) to analyse the level of pavement distress using the PCI method. The study area focused on the road Sections 43.7 & 44, FT005 Pengkalan Raja, Pontian. In this study, UAV is used as an alternative in visual road inspection work for data acquisition in pavement distress detection. This study has a low-cost, flexible system that is simple to use and can capture fully automatic road visuals. The use of UAVs as a verification medium is more efficient than the conventional method. It is advantageous because it saves money [6]. It can produce more accurate results because it measures every end and vertex of the road using a digitising method, whereas the conventional method measures from vertex to the vertex of the road using a theodolite [7].

2. METHODOLOGY

The methodology consists of four fundamental stages: flight planning, data collection, image processing, and data analysis.

2.1 Data Collection

Grid mission was used as a pattern in this study to capture the image for the road. The mission is carried out with the help of Pix4Dcapture, which must be installed on a smartphone. This application will aid in the smooth operation of flights. Only one person can operate the UAV remote control to collect data. Figure 1 shows the flight pattern grid. Before beginning the flight mission, the flight height must be determined.

The UAV was flown from a height of 30 meters above ground level. The road grid size is set to 46 x 359 m. Using this application, the UAV will fly at a medium speed for this mission. The Pix4dcapture application was used to control the UAV as a whole. The most important thing to do during the flight mission was to ensure that the UAV's Global Positioning System (GPS) was connected to the smartphone via the Pix4dcapture application.

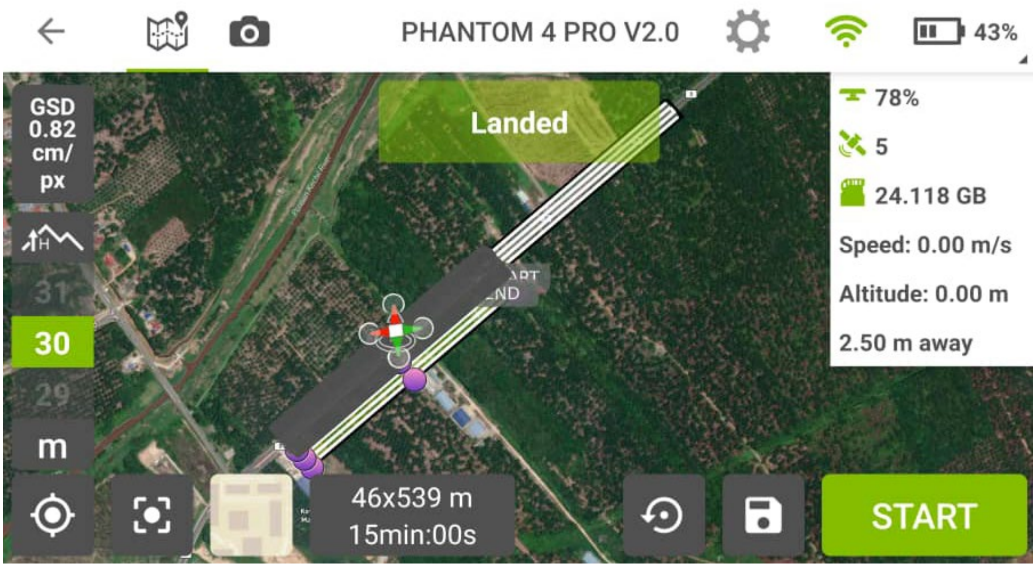

Figure 1. The image of a road with grid mission flight using Pix4Dcapture.

2.2 Image Processing

The image of the road taken via UAV using the Pix4Dcapture application installed in the smartphone was processed using the Pix4Dmapper software to produce orthomosaic Photo and Digital Surface Model (DSM). Pix4Dmapper will combine all the photos taken by the UAV. There were 728 images of the road.

Pix4DMapper generated orthomasaic images and Digital Surface Model (DSM) from the UAVs. Data transferred to the computer was entered into Pix4DMapper for processing. The data were then processed in three stages by Pix4DMapper, namely Level 1: Initial Processing, Level 2: Cloud and Mesh Points, and Level 3: Digital Surface Model (DSM), Orthomosaic and Index [8]. Prior to generating the orthomosaic, Pix4D generated a 3D point cloud. The point cloud was generated from the 728 images. The point cloud can be edited to remove any spurious points. The point cloud looks quite pixelated, so there is an option in Pix4D to view a 3D mesh instead. The 3D mesh is a 3D model where all the point cloud dots are connected to create a surface. This point connection can be seen in Figure 2.

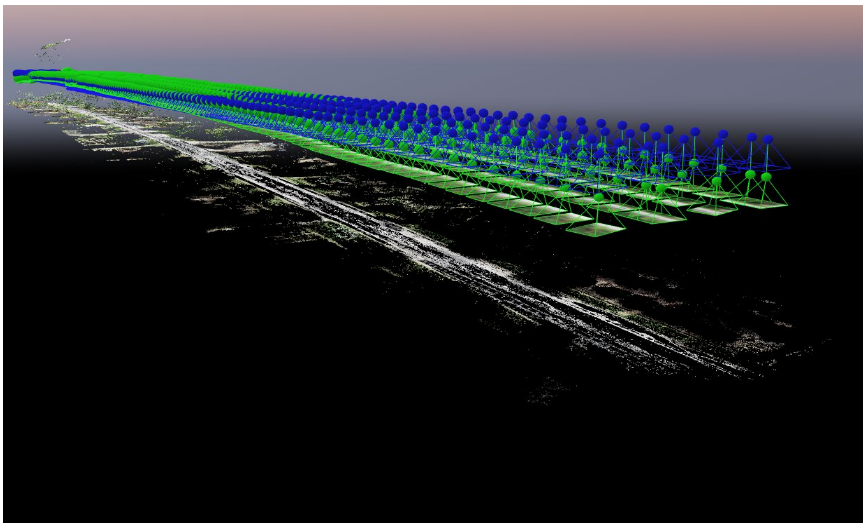

Figure 2. The mesh stage during the image processing.

These three processes produced the orthomosaic image shown in Figure 3. The zoom-in image is the UAV image that can be seen using the orthomosaic image.

Figure 3. Orthomosaic images produced using Pix4DMapper.

2.3 Developing Pavement Distress Data

Using the software Global Mapper, the user can perform and identify pavement distress on orthomosaic images and DSM to find the information needed. In order to make it easier and to know the exact position of each pavement distress, the study area was divided into five sections at a distance of 200 m for each section.

The following information is required to determine pavement distress: width, length, area, depth, location, severity level and types of pavement distress based on orthomosaic and DSM images. For all sections, the same method was used to determine the distressed pavement. Figure 4 shows information to determine the pavement distress.

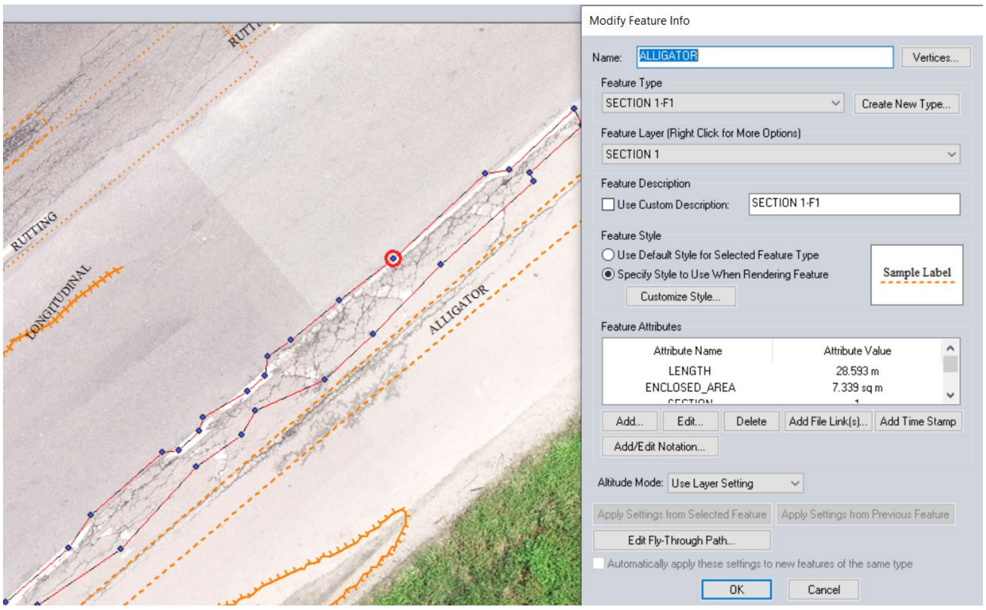

Figure 4. Determination of the pavement distress data

3. RESULTS AND DISCUSSION

The following are the findings focused on in this study—first, a query for pavement distress. Second, the severity level of pavement distress using the PCI method.

3.1 Query Analysis for Pavement Distress

Query pavement distress is a question addressed if an authority or anyone wanted to obtain information for pavement distresses. Attribute data can be used to obtain the information. This is because the data is automatically saved in the Global Mapper software. If anyone wants to determine the pavement distress location, select the data, and the location will be displayed as shown in Figure 5. Depending on the situation, the same method was used to obtain query analysis.

Figure 5 shows the example of a query to determine the location of the high severity level pavement distress in section 1. The severity level of pavement distress is divided into three categories: low (L), medium (M), and high (H). Section 1 will provide an example of a high severity level for this query. An example of a query is as follows:

> "How to obtain pavement distress data in Section 1, at a high (H) severity level?".

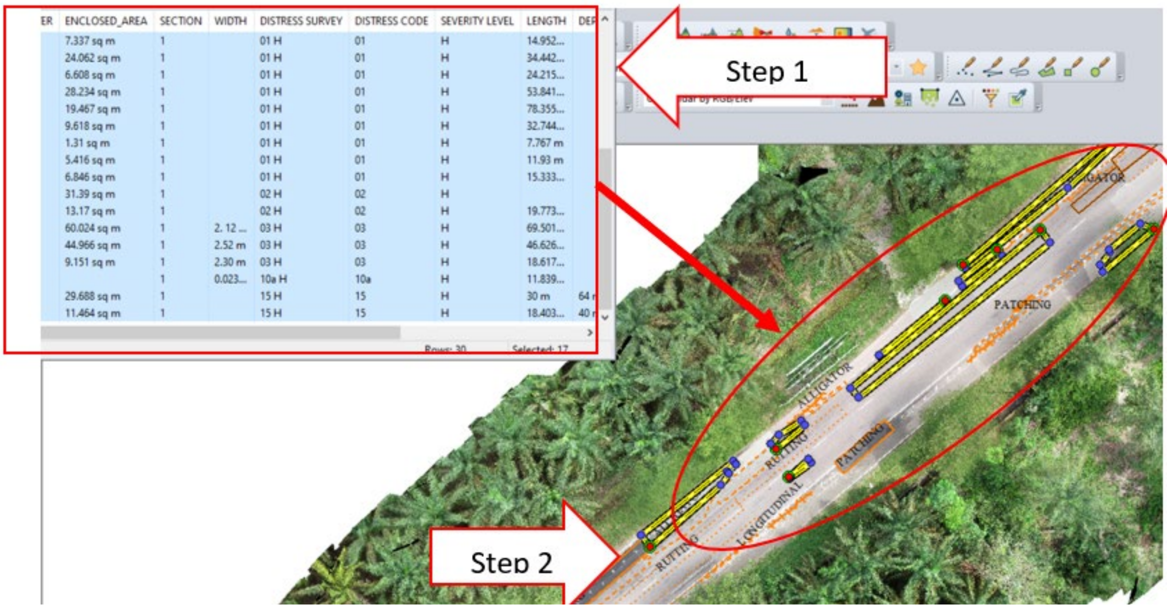

Figure 5. Steps to determine the location of pavement distresses.

The data obtained from Figure 5 represents the location of all types of pavement distresses that are at a high level of severity in Section 1.

3.2 Summary for the Types of Pavement Distress in Each Section

The attribute data is automatically saved in the Global Mapper software. Next, the obtained attribute data were exported to Excel to generate graphs, which will be used when analyzing pavement distress using the PCI method. Figure 6 shows one of the exported data attributes to Excel.

The graph was created using the type of pavement distress data and total pavement distress. The term “type of pavement distress” refers to each type of pavement distress, while “total pavement distress” refers to the sum of all types of pavement distress that occur in that section.

NAME	LOCATION	PERIMETER	AREA	SECTION	WIDTH	DISTRESS SURVEY	DISTRESS CODE	LENGTH
ALLIGATOR	SECTION 1-F23		9.618 sq m	1		01 H	1	32.744 m
ALLIGATOR	SECTION 1-F16		24.062 sq m	1		01 H	1	34.442 m
ALLIGATOR	SECTION 1-F7		33.339 sq m	1		01 H	1	106.87 m
BLEEDING	SECTION 1-BG6		1.077 sq m	1		02 L	2	4.601 m
BLEEDING	SECTION 1-BG5		6.097 sq m	1		02 M	2	18.321 m
BLEEDING	SECTION 1-BG4		13.17 sq m	1		02 H	2	19.773 m
BLEEDING	SECTION 1-BG3		1.097 sq m	1		02 L	2	4.451 m
BLEEDING	SECTION 1-BG 2		5.77 sq m	1		02 M	2	11.596 m
BLOCK	SECTION 1-BK4		12.941 sq m	1	1.71 m	03 M	3	16.716 m
BLOCK	SECTION 1-BK1		60.024 sq m	1	2. 12 m	03 H	3	69.501 m
BLOCK	SECTION 1-BK3		44.966 sq m	1	2.52 m	03 H	3	46.626 m
BLOCK	SECTION 1-BK6		10.162 sq m	1	13.63 m	03 M	3	13.63 m
LONGITUDINAL	SECTION 1-LL3			1	0.0046m	10a L	10a	12.116 m
LONGITUDINAL	SECTION 1-LG6			1	0.0074 m	10a M	10a	7.964 m
LONGITUDINAL	SECTION 1-LG7			1	0.0063 m	10a M	10a	6.835 m
LONGITUDINAL	SECTION 1-LG8			1	0.006 m	10a M	10a	9.104 m
LONGITUDINAL	SECTION 1LG5			1	0.006m	10a L	10a	3.191 m
LONGITUDINAL	SECTION 1-LG9			1	0.023m	10a H	10a	11.839 m
PATCHING	SECTION 1-P5		20.242 sq m	1		11 L	11	35.62 m
PATCHING	SECTION 1-P2		4.337 sq m	1		11 M	11	8.699 m

Figure 6. Attribute data in Excel form.

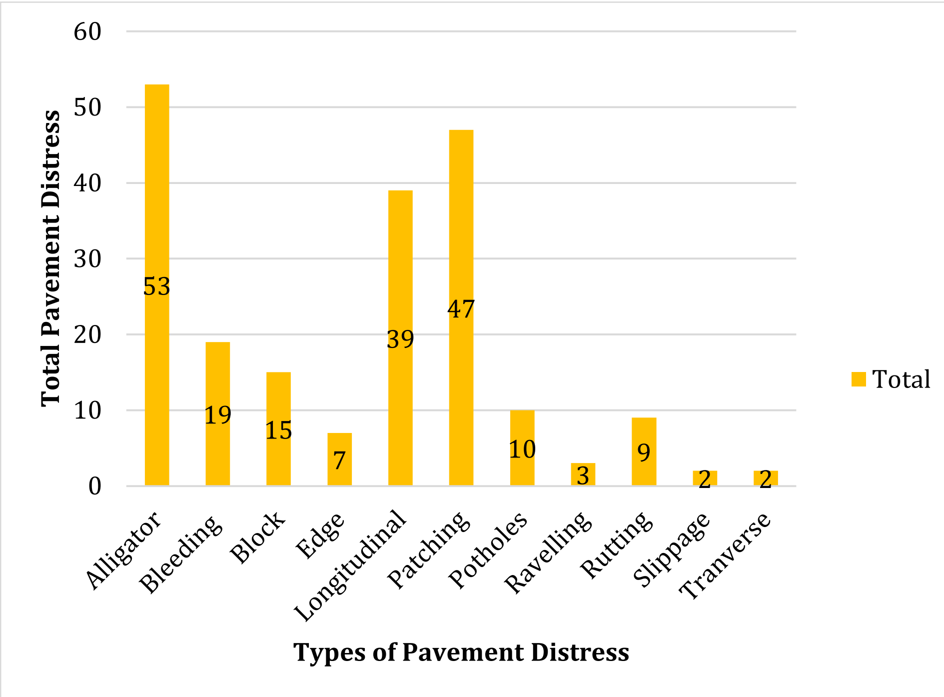

Figure 7. The histogram of all sections for the types of pavement distress vs total pavement distress.

Figure 7 shows the total distress survey for all sections. The data shows that out of the 19 distress types, 11 types were encountered on the subject road. The quantities of distress areas are listed according to the type of distress and also indicate the total pavement distress. Among all the distresses, alligator cracking and patching contribute the highest number of occurrences, 53 and

47, respectively. This high distress occurred because the road is the main federal road connecting the people of Pontian and nearby areas to Johor Bahru and Singapore. The area has long been a hot topic of discussion in newspapers and social media due to the cracking problem on this road [9]. According to Figure 7, cracking is the highest cause for this road. This phenomenon is because cracking is the most common and serious type of distress that affects all asphalt pavements [10].

This road was constructed on soft soil. Various maintenance types, such as regulation, resurfacing, CIPR, and others, are performed on that road each year. However, it did not solve the problem because the maintenance performed is only temporary, because they only performed on the road's pavement surface. Those maintenances also result in additional loads on the road base surface. The crack will become wider as the load increases. Furthermore, during peak hours, this road sees a significant increase in traffic, which is one of the causes of cracking [9]. Therefore, the PCI method was used to determine the level of pavement distresses in this study area, which is then followed by appropriate maintenance recommendations based on the road's level of service.

3.3 Severity Level of Pavement Distress using PCI Method

Pavement Condition Index (PCI) is used to evaluate the condition of the pavement based on a simultaneous assessment of the type of distress, density and severity. The pavement condition index (PCI) is a numerical index ranging from 0 to 100 that indicates the overall condition of the pavement, 0 for failed pavements and 100 for new pavement conditions [11]. It is widely used in civil engineering. Figure 8 shows the index's ratings.

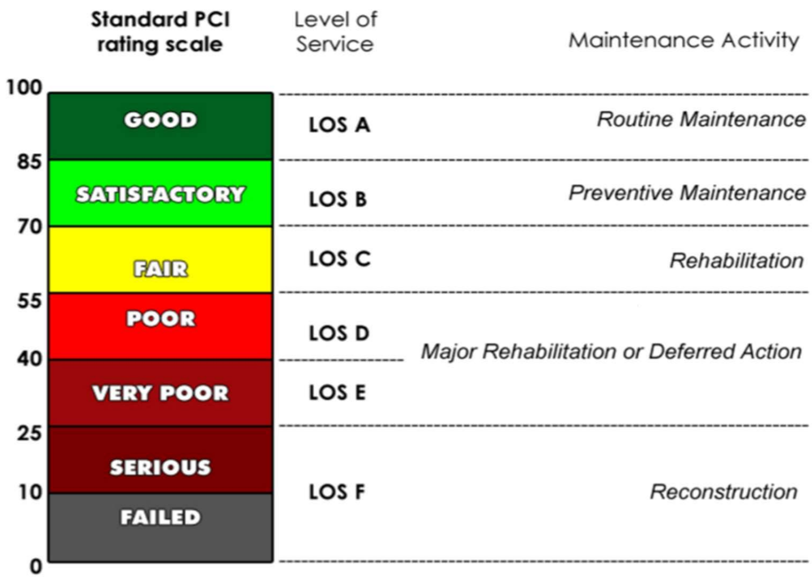

Figure 8. Pavement Condition Index (PCI) rating scale.

The following are the steps to enter pavement distress data obtained from attribute data [11]:

1. Add the totals for each distress type at each severity level and record them on the calculation sheet under "Total."
2. To calculate the percentage of density per sample unit for each distress type and severity, divide the quantity of each distress type at each severity level by the total area of a sample unit and multiply by 100.
3. Using the distress deduct value curves, calculate the deduct value for each distress type and severity level combination. The deduct value graph used for this study, to determine the deduct value for each type of distress. One of the deduct value curve is shown in Figure 9 to determine the deduct value for the type of alligator cracking.

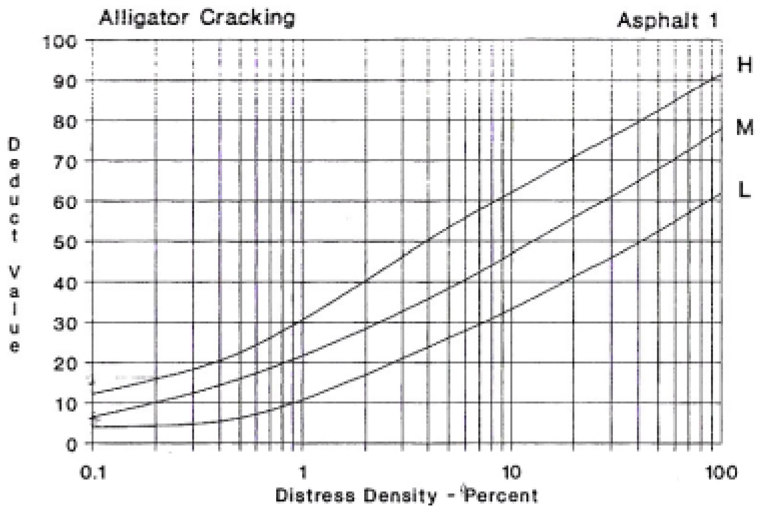

Figure 9. Deduct Value Curve for Alligator Cracking.

After the data in the calculation sheet is entered, then determine the maximum allowable number of deducts (m). Following is a description of each step:

1. If only one individual deduct value (or none) is greater than 5 for airfields and unsurfaced roads, the total deduct value is used in step 4 instead of the maximum corrected deduct value (CDV), and the PCI computation is completed; otherwise, the following steps should be taken.
2. List the individual deduct values in descending order.
3. Using the following formulas, determine the allowable number of deductions.

$$m_i = 1 + (9/98)(100 - HDV_i) \qquad \text{(for surfaced road)}$$

where:
m_i = allowable number of deducts, including fractions, for sample unit *i*.
HDV_i = highest individual deduct value for sample unit *i*.

4. Calculate the maximum corrected deduct value (CDV), which is calculated iteratively as follows:
   a. Determine the number of deducts greater than two for surfaced roads.
   b. Add all individual deduct values to get the total number of deduct values.
   c. Determine the CDV from q and the total deduct value by consulting the appropriate correction curve, as shown in Figure 10.

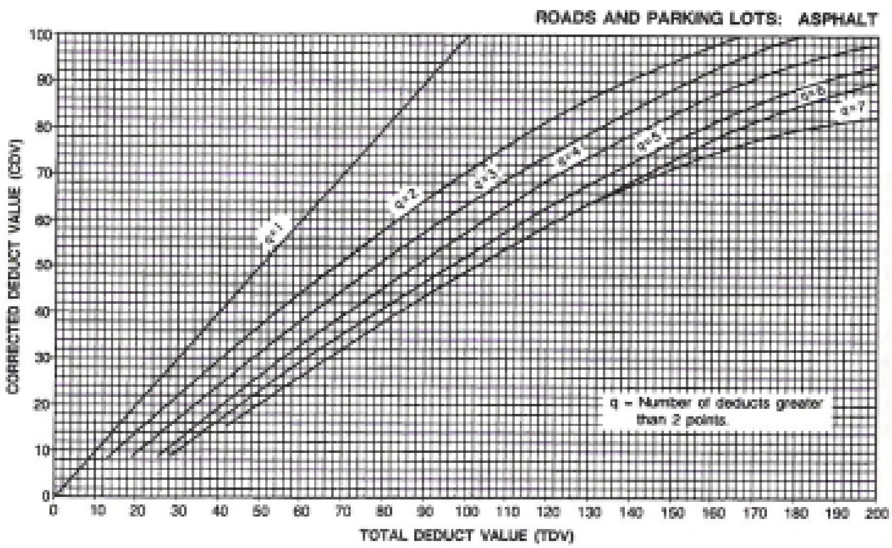

Figure 10. Correction Curve.

   d. For surfaced roads, reduce to 2.0 the smallest individual deduct value greater than 2.0, then repeat steps a–c until q equals 1.
   e. The maximum CDV is the highest of the determined CDVs.
5. Calculate PCI by subtracting the maximum CDV from 100

An example of a PCI calculation for Section 1 that used the obtained attribute data shown in Table 1. The table below shown the analysed data for Section 1 to aid in the calculation of PCI. The following are steps to calculate the pavement condition index for pavement distress in Section 1.

Table 1 Calculation Sheet for Section 1

CALCULATION SHEET
PAVEMENT CONDITION INDEX
LOCATION: FT005, JOHOR BAHRU-MELAKA
SECTION: 1
ROAD WIDTH (m): 15 × 200 = 3000

DISTRESS SURVEY	QUANTITY															TOTAL	DENSITY %	DEDUCT VALUE
01M	1.54	2.42	16.3	13.49	2.14											35.89	1.19633333	22
01H	5.47	9.62	24.06	33.34	7.34	19.47	6.85	28.23	6.61	12.58	2.27	16.87	1.31	5.42	1.16	180.6		
01H	3.41	6.05	9.41	2.89	4.92	7.34										34.02	1.134	31
02L	1.07	1.1														2.17	0.07233333	0
02M	6.1	5.77														11.87	0.39566667	2
02H	31.39	13.17														44.56	1.48533333	5
03M	12.94	12.13	10.16	21.45												56.68	1.88933333	6
03H	60.02	44.97	9.15													114.14	3.80466667	18
10a L	0.0046	0.006														0.0106	0.0053	0
10a M	0.0074	0.0063	0.006													0.0197	0.00985	0
10a H	0.023															0.023	0.0115	5
11L	20.24	0.937	15.96	6.02	75.7	5.04										123.897	4.1299	7
11M	4.34	1.48	10.66	4.12	5.56											26.16	0.872	8
15L	20.33	37.53	3.83	31.47												93.16	3.10533333	17
15M	2.61	32.7	19.94	11.12												66.37	2.21233333	26
15H	11.46	29.69														41.15	1.37166667	29
19M	0.11	0.14														0.25	0.00833333	5
19H	0.25															0.25	0.00833333	7

Maximum allowable number of deduct, m

- Highest deduct value, HDV = 58
  m = 1 + (9/98)(100– HDV)
  m = 1 + (9/98)(100–58)
  = 4.9

- Deduct values in descending order: 58, 29, 26, 22, 18, 17, 8, 7, 7, 6, 5,5,2
- Number of deduct values = 8

Maximum corrected deduct value, CDV

- Number of value greater than 2, q = 12
- Total deduct value = 58 + 29 + 26 + 22 + 18 + 17 + 8 + 7 + 7 + 6 + 5 + 5 = 208

CDV =

No.	Deduct values												Total	q	CDV
1	58	29	26	22	18	17	8	7	7	6	5	5	208	12	0
2	58	29	26	22	18	17	8	7	7	6	5	2	205	11	0
3	58	29	26	22	18	17	8	7	7	6	2	2	202	10	0
4	58	29	26	22	18	17	8	7	7	2	2	2	198	9	0
5	58	29	26	22	18	17	8	7	2	2	2	2	193	8	0
6	58	29	26	22	18	17	8	2	2	2	2	2	188	7	81
7	58	29	26	22	18	17	2	2	2	2	2	2	182	6	86
8	58	29	26	22	18	2	2	2	2	2	2	2	167	5	84
9	58	29	26	22	2	2	2	2	2	2	2	2	151	4	83
10	58	29	26	2	2	2	2	2	2	2	2	2	131	3	80
11	58	29	2	2	2	2	2	2	2	2	2	2	107	2	75
12	58	2	2	2	2	2	2	2	2	2	2	2	80	1	80

Maximum CDV = 86
Determine the Pavement Condition Index
PCI = 100– CDVmax
= 100– 86
= 14
Based on the rating for PCI value of 14, this section of pavement is in serious condition.

The same procedure is followed for the other sections. The results for the five sections are shown in Table 2.

Table 2 Summary of Severity Level

	Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**
Pavement Condition Index (PCI)	14	11	20	11	100
Level of Service (LOS)	LOS F	LOS F	LOS F	LOS F	LOS A
Maintenance Activity	Reconstruction	Reconstruction	Reconstruction	Reconstruction	Routine maintenance

The research work yielded a satisfactory result in that the desired objectives were completely met. Figure 11 shows a comparison of images captured in the study area with cameras and drones. The image captured by the drone and the image captured by the camera is similar. This similarity demonstrates that the drone is capable of producing high-quality images. It makes determining the pavement distress easier. Besides that, the condition survey also completed successfully, and the PCI value and pavement distress quantities were calculated. Table 4.4 shows the results of the pavement condition index PCI for each section. The PCI pavement condition index for Section 1 is 14 and Section 3 is 20, and the PCI pavement condition index for Sections 2 and 4 is 11. These four sections necessitate reconstruction work. Section 5 has a PCI pavement condition index is 100, indicating that routine maintenance is required. Finally, a reconstruction work policy is recommended for Sections 1 to 4 because the PCI value of the road is below 40, with a LOS F.

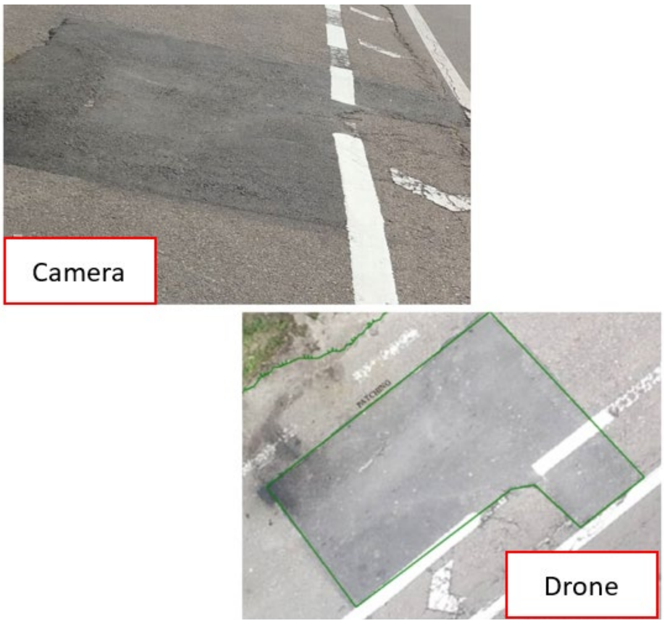

Figure 11. Comparison of images captured with drone and camera.

4. CONCLUSION

In conclusion, this study was carried out as a method for pavement condition inspection using an Unmanned Aerial Vehicle (UAV). The use of UAVs is intended to facilitate inspection work without endangering workers who are exposed to traffic congestion, hot weather, and other hazards. The study was conducted at Sections 43.7 & 44, FT005 Pengkalan Raja, Pontian. For the elevation of the flight, pavement images were taken at a height of 30 metres. This study introduces the use of UAVs as an alternative method of obtaining information and detecting various types of pavement distress that occurs on the road surface. Furthermore, combining information from the UAV with software such as Pix4Dmapper and Global Mapper can help to determine the type of pavement distress more quickly. As a result, this method can simplify data collection and analysis while saving time and energy. Conventional methods, such as manual walking surveys, are still used, but this method are slow because they can only collect a small amount of data per day, expensive because many employees are required to collect data, and the data collected is more subjective and less accurate because it is influenced by the evaluator's experience. Therefore, the use of micro UAV aircraft in road inspection work should be use as a primary option for obtaining pavement distress data more quickly. Furthermore, frequent road inspections should be performed to ensure that the road structure is always safe and can prevent any unwanted things from happening to road users.

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