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Implementation of UAV for Pavement Functional Performance Assesment

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Abstract: Pavement conditions could be degraded throughout its service life. Hence, a pavement management system is needed to ensure pavement performance according to its design life. To support a reliable pavement, a pavement condition survey needs to be conducted most effective and practical way. One of the technologies used in pavement condition surveys is the Unmanned Aerial Vehicle (UAV) or known as drone. The use of UAVs for road maintenance will reduce the cost and time and with the 3D model, the accuracy level is at the centimeter level which indicates UAVs are an excellent and promising tool for road work. In this study, a PCI method of pavement condition evaluation will be used to asses pavement through both manually surveyed and 3D model calculation with the use of Agisoft application. Later on, statistical test will be carried out such as ANOVA and correlation to determine the relationship between pavement condition obtained from two different survey method as well as the comparison in identifying pavement distresss, PCI value and pavement condition. In result, those two methods can identify identical types of damage, with a fairly high percentage of > 60%. While, manual method could identify a higher percentage of degree of severity than 3D model with the help of application. The manual of pavement condition assessment can identify in more detail than the Agisoft Metashape application. Based on statistical tests, the two methods used show a close and unidirectional relationship.

Keywords: UAV, 3D model, manual, pavement condition

1. Introduction

Pavement performance changes over time. During the design process, it is well known that pavement is usually designed for 15 or 20 years of service. During pavement service period there might be changes in traffic growth, increased rainfall and mismanagement of pavement that would decrease life service of pavement. A pavement management system is a tool to help engineers and policymakers in managing pavement to fulfil its service life. Pavement distress and roughness data represent pavement functional service and become input in pavement management system to determine the most appropriate maintenance from a technical and budgeting point of view.

The method of pavement survey tool is still based on a vehicle with sensors and processing tools attached. There are few limitations to this method of survey such as expensive and troublesome survey, while cost and safety considerations require that it be done at regular intervals (Zhang & Elaksher, 2010). In the visual pavement distress survey, raters walk along the pavement section and manually draw a map showing the type and exact location of all

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defects present on the pavement surface. The severity level of each distress is identified and recorded on the maps and the data sheets included in the Field Manual for Distress Surveys (M.Ho, J.Lin, C.Huang, 2020). For last decades, another method of pavement survey has gradually been researched, such as using an unmanned aerial vehicle (UAV). The image analysis acquired by innovative and rapid systems such as drones is a useful method for road infrastructure managers. The goal of these innovative methods is certainly to reduce the time for identifying the surface pavement distresses, but above all to reduce the investigations costs (Leonardi et al., 2019). Applications of UAV for pavement condition and road distress monitoring have been reviewed and showed that the use of UAV is still in the development phase and not yet in practice (Outay et al., 2020). The Covid 19 pandemic in the last three years can be used as the moment to use of technologies such as the Internet of Things (IoT), UAV, blockchain, Artificial Intelligence (AI), and 5G, among others, to help mitigate the impact of the COVID-19 outbreak (Chamola V, 2020). UAV can offer many advantages, not only ensure minimized human interaction, but also be used to reach inaccessible areas.

The use of drone for pavement distress was carried out by Zhang (2008) took the damage to an unpaved road using UAV. The photos that are displayed in 2D are able to show road damage by interpreting aerial photos through shapes, patterns, colors, and image classification. This research has not discussed much technically about the process and the results of 3D aerial photography. However, mentioning the importance of 3D models to identify road damage, because only through a 3D view can be obtained the slope of the road: slopes/inclines (vertical geometry), bends (horizontal geometry), and potholes. In a subsequent study, Zhang (2012) built a 3D model through the reconstruction of aerial photographs using a UAV to assess the damage to unpaved roads. The resulting 3D model shows that road damage can be interpreted from the irregular shape and texture of the ground surface, as well as different surface heights that are displayed through different colors. In this study, there are still some errors in interpretation results caused by the shadow factor being taken during shooting, and due to the low spatial resolution of the camera, the texture of the ground surface in the 3D model to be less visible. The use of drone for pavement distress was carried out by Leonardi (2019), 25 m height was taken to obtained a good picture. Later, black and white color interpretation using MATLAB was used to identify pavement distress from aerial photos (Leonardi et al., 2019). Another research showed that a 3D model from aerial photography using a UAV can identify type of pavement distress, calculates the dimensions of the pavement distress area and the depth/height of the road, and detects road unevenness automatically using the Region Growing Algorithm (Tan & Li, 2019). The results of 3D model with measurement in the field was at the centimeter level which indicates UAV is an excellent and promising tool for road work.

The use of UAV in Indonesia was observed and able to identify 6 types of pavement distress and calculate the extent of pavement distress (Mandaya, 1978). This study resulted 96,36% of an accuracy and UAV can be relied for inspection of types of distress on the flexible pavement (asphalt), inexpensive, flexible, easy to operate and produce high-resolution images. In another research, it is found that 3D model from orthophoto can be used to calculate the dimensions of the pavement distress planimetrically (X, Y) and the depth (h) of pavement distress with a precision of 0.3cm to 3cm to the value of the measurement results in the field (Astor et al., 2022). Moreover, road gradients didn't affect the 3D model nor the pavement distress calculation. Another study found that the use of UAV for road maintenance gives precision of 96,57% and could identify pavement distresses such as racks, depression, potholes, raveling, shoving, corrugation and unpaved surface. The study proposed that the use of UAV for road maintenance will reduce the cost and time. Though there are more to analyzed and developed, the use of UAV is promising and advantageous (Singh, 2017). More detailed analysis were needed to interpret UAV data into reliable data for evaluating pavement condition, deep learning technology was one of the detailed analysis (Wu et al., 2019). Several algorithms and neural networks analysis were taken to validate data in identifying and classifying distress types.

Pavement distress assessment in Indonesia, specifically in study site Cikalong-Cipeundeuy road in Cikalongwetan District West Bandung Regency West Java, still carried out manually by surveying in the field using the Pavement Conditions Index (PCI) or Surface Distress Index (SDI) method based on the visual road condition survey which identified the type of distress, severity, and quantity. The PCI method is the most widely used index for pavement condition assessment throughout the United States and Canada. It is a comprehensive measure of the present pavement condition that is based on the observed surface distresses and sound statistical analysis for pavement sampling. It also indicates the pavement structural integrity and surface operational condition (Elhadidy et al., 2021)(Shahin, 2020). Data for PCI rating were collected through visual inspection or image-based survey methods which requires long-time and traffic interruption. This method is rather impractical for long roads and large road networks as well as put surveyor unsafe during pavement inspection.

Thus, combination between visual inspection and the use of UAV should be done in filling the gap for more practical and reliable pavement inspection method. In this study, a PCI method of pavement assesment will be used to assess pavement through both manually surveyed and 3D model calculation with the use of Agisoft application. Later on, statistical test will be carried out such as ANOVA and correlation to determine the relationship between pavement condition obtained from two different survey method as well as the comparison in identifying pavement distresss, PCI value and pavement condition. Location of this study as follows on figure 1. This study is on 1 km of road length, where high to medium severity of pavement distress occurs. Pavement distress in location study as seen on figure 2.

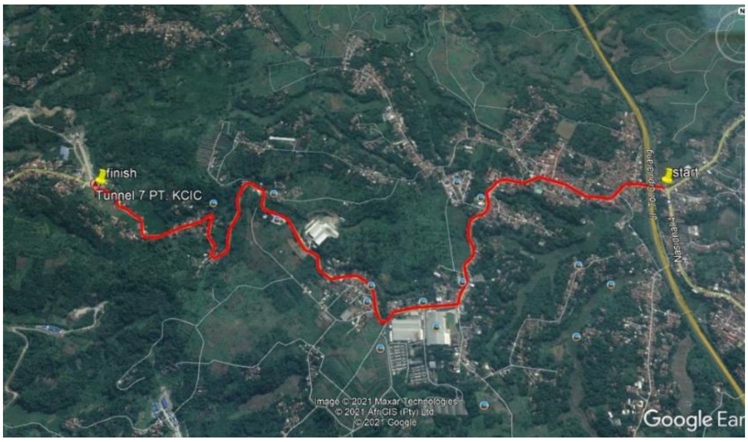


Fig.1 - Location of study

Fig. 2 - Pavement distresses in Cikalong-Cipeundeuy road

2. Materials and Method

The drone used in this study is the Phantom 4 Pro, which has a flight time of up to 30 minutes and has a Two-Frequency Signal Control 2.4 & 5.8Ghz with a range of 7km. The drone was flown at a height of 15m and an overlap of 60% to photograph a 1km road with a total of 6 Ground Control Points (GCP) (Figure 3).

Fig. 3 - Research object and GCP positions

Table 1 - GCP coordinates

GCP Name	Northing (m)	Easting (m)	Elevation (m)
Base fix	9254348,644	768523,280	678,99
GCP 1	9254898,007	769451,970	635,03
GCP 2	9254866,149	769276,335	641,69
GCP 3	9254878,578	769059,873	653,18
GCP 4	9254946,438	768905,434	659,328
GCP 5	9254888,788	768672,310	667,78
GCP 6	9254795,07	768652,412	668,72

The following is a 3D model produced in this study shown from the top view (Figure 4a) and side view (Figure 4b).

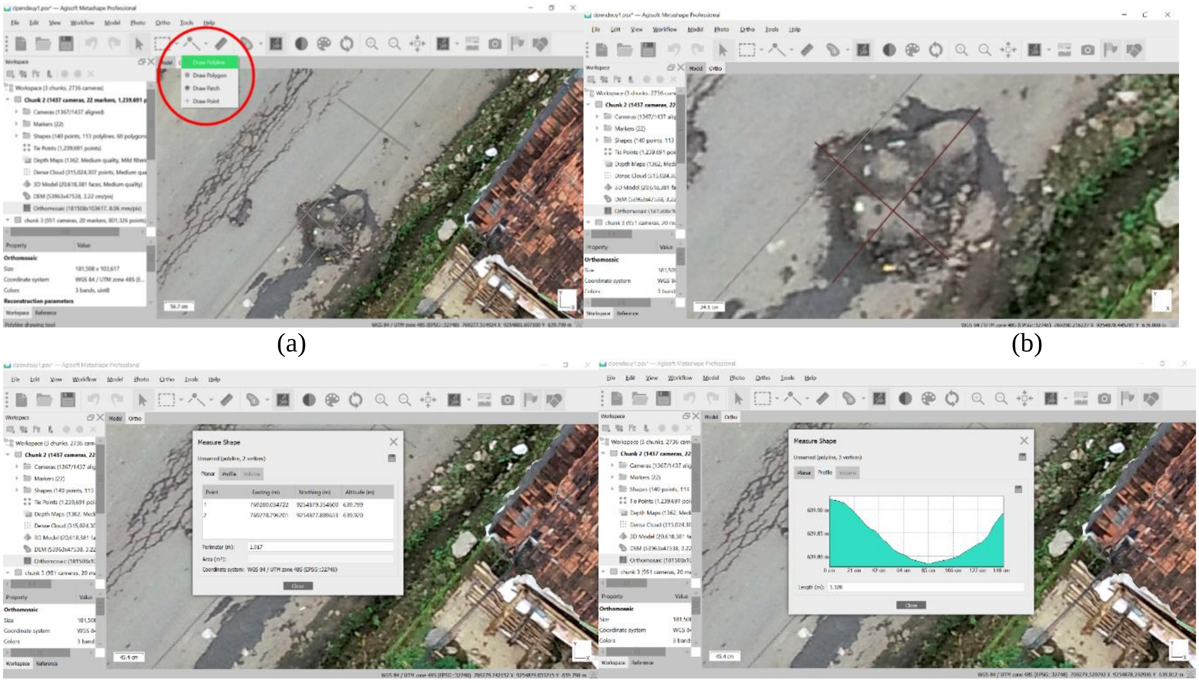
(a) **(b)**

Fig. 4 - (a) 3D Model (top view); (b) 3D Model (side view)

In the 3D model, interpretation and identification of the types of pavement distress are carried out. Furthermore, a comparison of the appearance of the type of damage in the 3D model with the conditions in the field is carried out. Figure 5 shows that the 3D model can show the condition of pavement distress clearly so it is very easy to identify the types of pavement distress that exist in the research location.

Fig. 5 - The results of the identification of the types of pavement distress in the 3D model (below) to the real conditions in the field (top). Left – Right: pothole, depression, edge cracking

In 3d model, distress type can be measured by using Tab draw polyline. Figure 6 gives illustration in measuring distress dimension, obtaining area or volume as well as contour. After obtaining related data for PCI value, the PCI rating calculation according to ASTM D6433 was conducted.



(a) (b)

(c) (d)

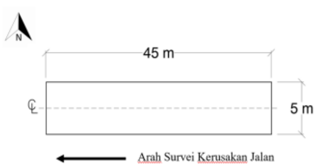
Fig. 6 - Steps for measuring distress; (a) tab draw polyline; (b) measuring; (c) measure shape and dimension; (d) contour

Meanwhile, data from visual inspection from the location study was also being calculated for PCI value and rating. In the loaction study, the first activity was to distribute sample units. Therefore, along 1 km area of study, it has 5 m width. Then, taken minimum area as consideration, it resulted 45 m length of 1 unit sample of which resulted 23 unit sample of 1 km of location study. Then, distress data was recorded on the given form in ASTM. In location study, there were found 9 out of 19 distresses and dominated with Alligator Cracking, Patching dan Potholes. Figure 7 shown an example for PCI form. In the form, density for each distress was calculated then deduct value was also obtained. After deduct value, calculation process continue with calculation of corrected deduct value (CDV) which maximum value of CDV indicates PCI value (equation 1).

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

Branch	:	Section	: 1	Sample Unit	: 1
Surveyed by	:	Date	: 4-Apr-21	Sample Area	: 225

1. Alligator Cracking	6. Depression	11. Patching&Util Cut Patching	16. Shoving
2. Bleeding	7. Edge Cracking	12. Pollshed Aggregate	17. Slippage Cracking
3. Block cracking	8. Jt. Reflection Cracking	13. Potholes	18. Swell
4. Bumps and Sags	9. Lane/Shoulder Drop Off	14. Railroad	19. Weathering/Raveling
5. Corrugation	10. Long and Trans Cracking	15. Rutting	



DISTRESS SEVERITY	QUANTITY										Total	Density	Deduct Value
7M	1.43	4.55	3.18	1.64	1.2						12	5.333333	10.5
10M	1.23										1.23	0.546667	2
1L	6.92 x 1.03	0.6 x 3.12	4.3 x 1.92	2.93 x 0.97							20.0977	8.932311	32
13M	1	2	3	4							10	4.444444	65
1M	2.24 x 0.93										2.0832	0.925867	22
19M	5 x 45										225	100	15
11L	0.87 x 1.85										1.6095	0.715333	3
13L	5	4									9	4	40

(a)

m	4.21429	<	5										
	3.15												
No	Deduct Value										Total	q	CDV
1	65	40	32	22	3.15						162.15	5	82
2	65	40	32	22	2						161	4	88
3	65	40	32	2	2						141	3	84
4	65	40	2	2	2						111	2	76
5	65	2	2	2	2						73	1	72
6													
7													
8													
9													
10													
											Max CDV	=	88
											PCI	=	12
											Rating	=	Very Poor

(b)

Fig. 7 - (a) PCI form first page; (b) PCI form page 2

$$PCI = 100 - Max\ CDV \quad (1)$$

In order to test hypothesis whether PCI value from field inspection and UAV gives same average value, an analysis of variance and correlation were added. Analysis of variance (ANOVA) were one of the most widely used statistical method for testing hypothesis. ANOVA is often used to test the significance of mean differences among different group of scores. If a difference between means is statistically significant, the difference is expected (with a certain probability) to reappear if the study is replicated. A nonsignificant difference implies that you cannot rule out the possibility that the mean differences that do exist in the sample data occurred by chance (Vieira, 2011). There are two hypothesis occurs, null hypothesis (H_0) and alternative hypothesis (H_1). ANOVA showed result of F and Fcrit which implies if F > Fcrit, alternative hypothesis (H_1) is accepted then null hypothesis (H_0) is rejected.

3. Results and Discussion

Pavement distress measurement using the Agisoft Methashape application was carried out on several segments that were not blocked by trees. From a total of 23 segments or Sample Units along 1 km, there were 13 segments for which PCI measurements can be performed. Then, the results of the analysis of the two methods were compared at the maximum corrected deduct value condition to see the difference between the two methods. The comparison matrix can be seen in the following table:

Table 2 - Comparison matrix for pavement condition

Segment	Parameter of PCI at Max CDV							
	Manual				Software			
	Distress type	Severity	PCI	Pavement condition	Distress type	Severity	PCI	Pavement condition
SU-1	Longitudinal and transversal cracking	Medium	12	Very poor	Alligator cracking	Low	3	Failed
SU-6	Depression	High	0	Failed	Depression	High	0	Failed
	Potholes	Medium	0	Failed	Potholes	Medium	0	Failed
SU-7	Alligator cracking	High	0	Failed	Block cracking	Low	0	Failed
SU-9	Alligator cracking	Medium	13	Very poor	Alligator cracking	Medium	13	Very poor
SU-11	Alligator cracking	High	0	Failed	Alligator cracking	High	0	Failed
SU-12	Alligator cracking	Medium	0	Failed	Alligator cracking	Medium	10	Failed
SU-13	Alligator cracking	High	9	Failed	Alligator cracking	High	9	Failed
SU-14	Alligator cracking	Medium	3	Failed	Alligator cracking	Low	6	Failed
SU-15	Alligator cracking	High	0	Failed	Alligator cracking	High	7	Failed
SU-18	Alligator cracking	High	3	Failed	Edge cracking	High	0	Failed
SU-19	Alligator cracking	Medium	0	Failed	Edge cracking	High	0	Failed
SU-20	Edge cracking	High	0	Failed	Alligator cracking	Medium	0	Failed
SU-21	Alligator cracking	Medium	0	Failed	Alligator cracking	Medium	4	Failed

In the analysis using the manual method, the majority of the damage was alligator cracking, which was 77% of the total types of damage that could be identified. The severity that can be identified from the manual method is the high severity degree of as much as 54% of the total damage. From the PCI analysis using the manual method, it was found that 85% were in failed conditions and 15% were in poor conditions.

Analysis of the condition of the pavement based on the PCI method with the help of the Agisoft Methashape application obtained the majority of the damage with the alligator cracking type, which is 69% of the total types of damage that can be identified. The severity that can be identified is a high level of severity as much as 46% and a low of as much as 23% of the total damage. From the PCI analysis with the help of the Agisoft Methashape application, it was found that 92% were in failed conditions and 8% were in poor conditions.

However, if you look at the type of damage that can be identified, although manual and software methods can identify identical types of damage, there are several segments that show different identification of damage. In segments 1, 7, 18, 19 and 20. There are differences in the identification of defects between manual and software methods. This is due to differences in the perception of surveyors and the sharpness of the image processing of the drone photo data.

In table 3, a resume of the pavement condition values is carried out based on the method, then it is seen that the entire sample has the same average and the ANOVA test is carried out as a determination of the analysis of the hypothesis to be accepted or rejected. The hypotheses to be tested are

H_0 = There is no difference in the average PCI scores using different methods. (The same)
H_1 = There is a difference in the average PCI scores using different methods. (Not the same)

Table 3 - PCI value for each segment

No	Segment	PCI Value	
		Manual	Software
1	SU-1	3	3
2	SU-6	0	0
3	SU-7	0	0
4	SU-9	13	15
5	SU-11	0	0
6	SU-12	4	4
7	SU-13	9	9
8	SU-14	6	3
9	SU-15	7	8
10	SU-18	0	0
11	SU-19	0	0
12	SU-20	0	0
13	SU-21	4	8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0,615385	1	0,615385	0,030208	0,863478	4,259677
Within Groups	488,9231	24	20,37179			
Total	489,5385	25				

To determine the accepted H_0 or H_1, the conditions that must be followed are as follows:
a) If F > Fcrit then H_0 is rejected
b) If F < Fcrit then H_0 is accepted
c) If significant or probability > 0.05, then H_0 is accepted
d) If significant or probability < 0.05, then H_0 is rejected

Based on the results obtained in the ANOVA test, where it is seen that F count < F crit = 0.03 < 4.259, which means H_0 is accepted and H_1 is rejected. As for the probability value, it can be seen that the probability value is 0.863 > 0.05. Thus the null hypothesis (H_0) is accepted.

In addition, a correlation analysis was also carried out and the results were obtained as shown in table 4. It can be seen that the correlation results show that there is a very close relationship, with the value of 0.949 between application assistance and manuals. The positive sign indicates that the relationship is unidirectional, which indicates if the PCI results with the help of the application are high, the manual PCI results will also be high.

Table 4 - Correlation manual vs software

	Manual	Software
Manual	1	
Software	0,949	1

4. Conclusion and Contribution

From the results of the analysis using the manual method and the help of the Agisoft Methashape application, the two methods can identify identical types of damage, namely in this case alligator cracking damage, with a fairly high percentage of > 60%. In identifying the degree of severity, the manual method can identify a higher percentage level than with the help of the Agisoft Metashape application. The identification of the severity of the Agisoft Metashape application is affected by the lack of high-resolution image processing and also limitations when the shooting process is covered by other objects. The pavement conditions obtained between the two methods showed uniform conditions, namely > 80% in failed conditions. However, the manual method has a very poor rating of >10% which gives an overview of the manual pavement condition assessment that can identify in more detail than the Agisoft Metashape application. Based on statistical tests, the two methods showed no difference in the average PCI scores obtained. In addition, the two methods used show a close and unidirectional relationship.

For further research, For further research, a review is still needed on other factors related to UAV operational methods such as operator, flying heights, and weather. Those factors are needed to define their effect on the accuracy of pavement condition assessments through image-based data collected from UAVs. So that more reliable results will be obtained and contribute positively to the pavement evaluation process at the project level

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