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Assessment of Building Roof Defects Using Unmanned Aerial Vehicle (UAV) and Condition Survey Protocol (CSP) 1 Matrix System

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Abstract: In Malaysia, inspecting the roof structure of a high structural building usually takes a long time and costs a lot of money. Furthermore, defects in difficult areas of the building are difficult to detect. As a result, this study was carried out at the Faculty of Civil Engineering and Built Environment (FKAAB), UTHM to assess the extent to which Unmanned Aerial Vehicle (UAV) can be used to inspect building roof structures and analysed the significant building defects to the level of functionality using the Condition Survey Protocol (CSP) 1 Matrix. DJI Phantom 4 Pro was the type of UAV used to capture images of the defect and then processed by Pix4Dmapper software. The processed defect images were analysed using the CSP 1 Matrix to determine whether the building's overall performance. Based on this study, FKAAB's overall roof condition was average, with a total score of 5.95. As conclusion, a UAV can be used to inspect buildings because all the defects on the roof structure can be identified from the images captured by the UAV and can be analysed using CSP 1 Matrix as an assessment for evaluating the defect and overall roof condition.

Keywords: Unmanned Aerial Vehicle (UAV), Condition Survey Protocol (CSP) 1 Matrix, UAV Inspection, Visual Inspection

1. Introduction

The building is a human-made structure with various forms and functions. When a building is constructed, it must be inspected and maintained to ensure that the building conditions are always in good condition. In many countries, the condition of a building is assessed and inspected based on a diagnostic of the degree of deterioration of the structure's components [1]. Visual inspection is the method used to detect defects in the first stage of a building inspection [2]. As engineers, we must determine whether the problems are the product of improper assembly, a natural event, or improper

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building maintenance. Visual examination can provide detailed information that can lead to the positive identification of the source of patent distress. In general, a high structural building is one that has seven or more floors [3]. Any defects or damage to the building are difficult to see with the naked eye at such altitude. Binoculars and cameras are typically the primary tools used in visual inspection of tall buildings [4]. Typical equipment used during the visual inspection includes special tapping hammer, crack gauge, magnifying glass, binocular and camera [5]. Defects that occur in locations that are difficult to see with the naked eye cause the building cannot be supervised properly and perfectly. Position that is difficult to detect such as on the roof that requires special equipment to approach the affected area and is difficult to deal with in the early stages because it is not visible to the naked eye [6]. Destructive and non-destructive testing are two other methods used in the inspection of high structural buildings (NDT). NDT is performed on high structural building structures using tools such as Ultrasonic Pulse Velocity Testing (UPV) and Infrared Thermography Testing (IRT) [7].

Therefore, this study was to popularise the use of a new tool to carry out inspection on high structural building which Unmanned Aerial Vehicles (UAVs) were used to assist in providing early inspections of high structural buildings prior to high-maintenance work. Recent advancements in UAV technologies have enabled the development of low-cost, high-performance UAV that can be used in a variety of technologies including visual inspection. UAV are a suitable option for quickly inspecting buildings because of their ability to take off and land vertically, and their lightweight design. UAV are also equipped with several sensors and a Global Positioning System (GPS) to enhance their navigation capabilities [8]. In this study, visual inspection as the most widely used inspection technique were observe to identify defects on the roof structure. Overall, this research can help everyone learn more about the different types of defects that can occur in high structural buildings that constructed with concrete and steel and also popularized the use of UAV, allowing everyone to enjoy this technology and use it to make inspection work more productive, efficient, cost-effective, and safe.

2. Equipment and Methods

Depending on the type of building, several methods exist for building inspection and determining the severity of damage. One of the most typical techniques for determining the condition of a structure and analysing data is visual inspection.

2.1 Selection of the Study Area

Building that being choose is Faculty of Civil Engineering and Built Environment (FKAAB), UTHM that have roof structure, which consist of concrete and steel. FKAAB building consist of eight levels and several blocks with pitched roofs and high roof structures that are difficult to access and inspect. Figure 1 shows the location of study area.

Figure 1: FKAAB Building

2.2 Methods

Method generally are followed by phase shown in Figure 2 below. Several methodological stages have been done, including planning and preparation, data collection on site, data processing and data analysis, for studying and achieving the objective.

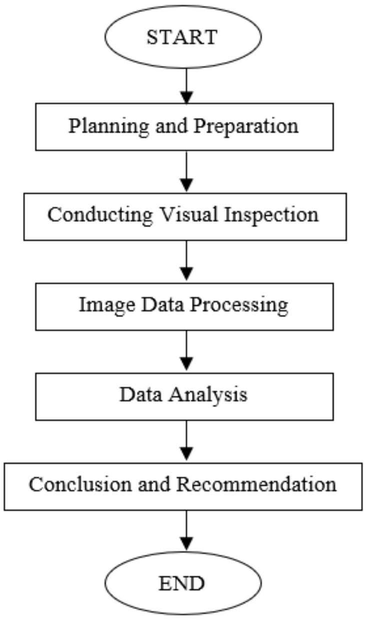

Figure 2: Flowchart of the study

a) Phase I – Planning and Preparation

The initial step in this study was to obtain information on the building from Pejabat Pembangunan dan Penyenggaraan, as well as approval from the officer in charge to inspect the roof structure. Observation at the study site was also required to find a suitable location with few obstructions so that the UAV could be flown easily. Figure 3 shows where the position that suitable for the UAV to be fly.

Figure 3: UAV position planning before take off

b) Phase II – Data Collection on site

Data collection on site was done by visual inspection. FKAAB have several blocks include Laboratory Block, Academic Block, Lecturer Block, Administrative Block, North Tower and South Tower. Because there were several different blocks with different heights in the FKAAB, the UAV flight is done manually so that the pictures obtained are of better quality and clearly visible and can identify any defects present on the roof surface. The aerial photos of FKAAB building also been captured by auto-flight mission to generate orthomosaic image, which was a part of the process of concept of photogrammetry in map production [9].

c) Phase III – Data Processing

Data taken through image capture using the UAV has been analysed for each image to ensure that the defects to the roof structure can be identified. Pix4Dmapper software was used to generate orthomosaic image of FKAAB building as shown in Figure 4. The orthomosaic image used to find out the position of the defects on the building block.

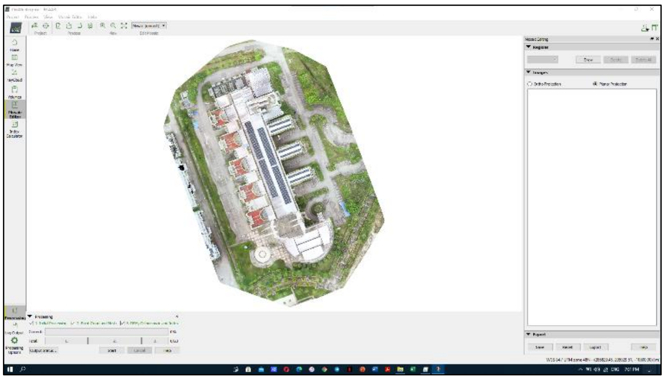

Figure 4: Interface for Pix4Dmapper image processing

2.3 Equipment

The equipment for data collection is shown below:

- DJI Phantom 4 Pro – The drone was used to capture the aerial photo of FKAAB and images of defect. Table 1 shows the specification of aircraft and camera of DJI Phantom 4 Pro.

Table 1: DJI Phantom 4 Pro Specification [10]

Type of UAV	Multi-rotor UAV
Weight (Battery & Propellers included)	1375 g
Diagonal Size (Propellers Excluded)	350 mm
Max. Flight Time	Approximate 30 minutes
Velocity Range	≤ 31 mph at 6.6 ft. (2m) above ground
Operating/Altitude Range	0 – 33 feet (0 – 10 m)
Obstacles Sensing	Front & Rear Obstacles Avoidance Left & Right Infrared Obstacles Avoidance
Sensor	1 CMOS Effective pixel: 20MP
Lens	FOV 84^{o} 8.8 mm/24 mm (35 mm format equivalent)
Maximal Opening	f/2.8 – f/11 auto focus at 1 m - ∞
ISO Range for Photo	100 – 3200 (Auto) 100 – 6400 (Manual)
Image Size	3:2 Aspect Ratio: 5472 × 3648 4:3 Aspect Ratio: 4864 × 3648 16:9 Aspect Ratio: 5472 × 3078

- DJI Go 4 – Flight planning application developed specifically for DJI drones. This application was functioning to do a flight planning for the related location to calculate a suitable flying height and capture images of defect manually.
- Pix4Dcapture – Flight planning application developed for auto-flight mission. This application was used to make an auto-flight mission for the UAV to capture aerial photo of FKAAB.
- Laptop - Used to run the professional photogrammetry software and data analysis.
- Pix4Dmapper - Professional photogrammetry software to generate orthomosaic image of FKAAB.

2.3 Equations

Equations used to achieve the total matrix value of the roof FKAAB building. The formula for the total score to obtained the building rate as shown in Eq. 1.

$$Total\ score = \frac{Total\ Matrix\ Value}{Number\ of\ Defects} \qquad Eq. 1$$

The score for the entire damage will be added and divided by the total damage to get the overall value of the condition of the building.

3. Results and Discussion

A total of 100 detectable defects were recorded on the roof structure of the FKAAB building. At the Laboratory Block, 28 defects had found. At the Academic Block, 14 defects had found. At the Lecturer Block, 9 defects had found. At the Administrative Block, 12 defects had found. At the North Tower, 16 defects had found and at the South Tower, 21 defects had found. The table 2 shows the overall number of defects for every type of defect on the roof structure of each blocks available.

Table 2: Type of defects detectable of roof structure

Block	Type of Defects / Defect Code	Number of Defects
Laboratory Block	D1 - Decolourise	14
	D2 - Mould Growth	5
	D3 - Water Ponding	3
	D4 - Cracking	4
	D5 - Vegetation Growth	2
Academic Block	D1 - Decolourise	5
	D2 - Mould Growth	3
	D3 - Water Ponding	2
	D4 - Cracking	2
	D5 - Vegetation Growth	2
Lecturer Block	D1 - Decolourise	3
	D2 - Mould Growth	3
	D5 - Vegetation Growth	3
Administrative Block	D1 - Decolourise	3
	D2 - Mould Growth	4
	D4 - Cracking	2
	D5 - Vegetation Growth	3
North Tower	D1 - Decolourise	1
	D2 - Mould Growth	5
	D4 - Cracking	5
	D5 - Vegetation Growth	5
South Tower	D1 - Decolourise	1
	D2 - Mould Growth	8
	D3 - Water Ponding	2
	D4 - Cracking	6
	D5 - Vegetation Growth	4

Images of the defects that have been capture manually by UAV need to edited obtain images of defect that clear as shown in Figure 5 (a-b).

(a) Image of defect before edit **(b) Image that edited**

Figure 5: Editing process for image of defect

All the detectable defects were placed in the Condition Survey Protocol (CSP) 1 Matrix table to determine the type of defect, the degree of the nature or condition of the defect and the degree of priority. The orthomosaic image of FKAAB in Figure 6 below was used to determine the position of the defect for each block in FKAAB to be evaluate in the CSP 1 Matrix table. Figure 7 shows the example of CSP 1 Matrix table for defect that can be found on the roof of South Tower of FKAAB.

Figure 6: Orthomosaic image of FKAAB building

<table>
<tr><td colspan="4">Photograph/Sketch No.</td><td colspan="2">92</td></tr>
<tr><td rowspan="10"></td><td colspan="3">Location</td><td colspan="2">South Tower</td></tr>
<tr><td colspan="3">Element/Component</td><td colspan="2">Roof</td></tr>
<tr><td colspan="5">CSP1</td></tr>
<tr><td>Condition</td><td>Priority</td><td colspan="2">Matric</td><td>Colour</td></tr>
<tr><td>4</td><td>4</td><td colspan="2">16</td><td></td></tr>
<tr><td colspan="5">Defect Description</td></tr>
<tr><td colspan="5">Cracking</td></tr>
<tr><td colspan="5">Recommendation</td></tr>
<tr><td colspan="5">Condition monitoring and maintenance</td></tr>
</table>

Figure 7: Example of CSP 1 Matrix table evaluating

Based on the Figure of CSP 1 Matrix table above, each detectable defect on the roof of FKAAB building were classified according to its condition and priority. For example, as Figure 7 which illustrates concrete cracking defect on the roof structure, the condition was scale 4 because the roof's condition was very poor and need major repair because the cracks that occur on the structure already can see the reinforcement bar, while the priority was scale 4 because the defect was major and it could lead to fatality as the reinforcement bar will rust and weaker the roof structure.

The schedule of FKAAB Building roof conditions using CSP 1 Matrix can be refer in Appendix A. Based on the schedule of FKAAB Building roof conditions using CSP 1 Matrix, the total matrix value from the assessment is 595. The overall roof condition rate of FKAAB building is 5.95 which is categorized as moderate level.

4. Conclusion

The study was conduct to popularise the use of UAV as an alternative measure to obtain a clearer image of defects especially in high sections. According to the study, using UAV as a tool makes building inspection work easier and more accurate. The use of UAV drone is in line with current technological developments that facilitate building inspection work. This can show that the first objective has been achieved which is to use UAV as a tool to conduct inspections in the FKAAB building. A total of 100 detectable defects on the roof structure can be identified on the FKAAB building. The process of capturing images of defects can be completed in a short period of time because UAV can fly to any location where the defects on the roof structure. This can show that the second objective has been achieved which is to identify, type of defects on the roof structure of FKAAB building from the images captured by UAV. In general, this study is only to provide an initial overview of the study building condition. From the data that has been analysed by using the CSP 1 Matrix to determine the overall roof condition, the roof condition of FKAAB building was in average rate that is 5.95 for overall matrix score. This can show that the third objective has been achieved which is to analysed the defect images by using CSP 1 Matrix to evaluating the defects and overall roof condition of the FKAAB building.

Nonetheless, this study has some limitations. When flying at high altitudes, the UAV used are prone to losing stability. This is due to the fact that the UAV used is a quadcopter with four blades. As a result, more stable UAV, such as the H520, can be used. The H520 is an eight-bladed hexacopter aerial system that has been developed specifically for commercial use and has proven to be a more stable, long flight time airframe with multiple payload options and advanced missing planning software. Other than that, the camera used is only capable of detecting damage. The damages are indistinguishable in thickness and depth. As a result, the use of cameras such as CGOET, which uses infrared radiation to determine the depth of a crack, can greatly aid in the production of high-quality images and data. The gimbal also can be added to get a better view without using expensive cameras. Only the DJI Phantom 4 Pro camera should be equipped with a gimbal. As a result, when capturing images of defects, UAVs are more stable.

Acknowledgement

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Appendix A

ASSESSMENT OF THE ROOF CONDITION OF FKAAB BUILDING						
No	Location	Defect Code	CSP1			
			Image No.	Condition Assessment [a]	Priority Assessment [b]	Matrix Analysis [c] (a + b)
A	Laboratory Block	D1	1	2	2	4
		D1	2	2	2	4
		D1	3	2	2	4
		D1	4	2	2	4
		D1	5	2	2	4

		D1	6	2	2	4
		D1	7	2	2	4
		D1	8	2	2	4
		D1	9	2	2	4
		D1	10	2	2	4
		D1	11	2	2	4
		D1	12	2	2	4
		D1	13	2	2	4
		D1	14	2	2	4
		D2	15	3	2	6
		D2	16	4	2	8
		D2	17	3	2	6
		D2	18	3	2	6
		D2	19	2	2	4
		D3	20	3	2	6
		D3	21	3	2	6
		D3	22	1	1	1
		D4	23	4	2	8
		D4	24	3	2	6
		D4	25	3	2	6
		D4	26	4	2	8
		D5	27	2	2	4
		D5	28	3	2	6
B	Academic Block	D1	29	2	2	4
		D1	30	2	2	4
		D1	31	2	2	4
		D1	32	2	2	4
		D1	33	2	2	4
		D2	34	4	2	8
		D2	35	4	2	8
		D2	36	3	2	6
		D3	37	4	2	8
		D3	38	3	2	6
		D4	39	4	2	8
		D4	40	4	2	8
		D5	41	4	2	8
		D5	42	3	2	6
C	Lecturer Block	D1	43	2	2	4
		D1	44	2	2	4
		D1	45	2	2	4
		D2	46	4	2	8
		D2	47	3	2	6
		D2	48	3	2	6
		D5	49	4	2	8
		D5	50	3	2	6
		D5	51	3	2	6
D	Administrative Block	D1	52	2	2	4
		D1	53	2	2	4
		D1	54	2	2	4
		D2	55	4	2	8
		D2	56	4	2	8
		D2	57	3	2	6
		D2	58	3	2	6

		D4	59	4	2	8
		D4	60	4	2	8
		D5	61	4	2	8
		D5	62	3	2	6
		D5	63	3	2	6
E	North Tower	D1	64	2	2	4
		D2	65	3	2	6
		D2	66	3	2	6
		D2	67	3	2	6
		D2	68	3	2	6
		D2	69	3	2	6
		D4	70	4	2	8
		D4	71	4	2	8
		D4	72	3	2	6
		D4	73	3	2	6
		D4	74	4	2	8
		D5	75	3	2	6
		D5	76	3	2	6
		D5	77	3	2	6
		D5	78	2	2	4
		D5	79	3	2	6
F	South Tower	D1	80	2	2	4
		D2	81	4	2	8
		D2	82	4	2	8
		D2	83	3	2	6
		D2	84	3	2	6
		D2	85	3	2	6
		D2	86	3	2	6
		D2	87	3	2	6
		D2	88	3	2	6
		D3	89	3	2	6
		D3	90	3	2	6
		D4	91	4	4	16
		D4	92	4	4	16
		D4	93	3	2	6
		D4	94	3	2	6
		D4	95	3	2	6
		D4	96	3	2	6
		D5	97	2	2	4
		D5	98	3	2	6
		D5	99	3	2	6
		D5	100	3	2	6
Total Matrix Value [d] = ∑[c]						**595**
Number of Defects [e]						**100**
Total Score [f] = (d/e)						**5.95**

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