Accuracy Assessment of Detecting Cracks on Concrete Wall at Different Distances using Unmanned Autonomous Vehicle (UAV) Images

Sharifah Norashikin Bohari*, Ain Uzzairah Amran¹, Nurul Ain Mohd Zaki¹, Muhammad Safwan Suhaimi¹ and Abdul Rauf Abdul Rasam²

¹ Faculty of Architecture, Planning & Surveying, Universiti Teknologi MARA, Perlis Branch, Arau Campus, 02600 Arau, Perlis, Malaysia
² Faculty of Architecture, Planning & Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

Email: shnorashikin@gmail.com

Abstract. Distance plays an essential role in determining crack detection. Without proper or fixed value of length, the time taken to capture the image of a crack may increase. It is essential to know the capability of Unmanned Autonomous Vehicle (UAV) to capture images for detecting cracks at different distances as it may be useful for building inspection, especially as it shortens the time taken to inspect cracks on buildings. This paper aims to analyze the accuracy of the UAV image in detecting cracks at different distance measurements qualitatively and quantitatively. The observed UAV images of the concrete wall starting from 1m until 6m distances were obtained. The images were processed using Agisoft software, while the edge detection algorithm of the Digimizer software was used for the crack width detection process. It was found that in detecting cracks at different distances, the hairline crack was visible at 3 meters, the narrow crack at 5 meters, and the medium crack at 6 meters. The relationship between distance and size of crack allows for a better understanding on how distance affects the detection of the crack which may be useful for building inspections or in the engineering sector.

1. Introduction

Due to rapid growth and modernization, the world has seen many huge and tall buildings. In a fast-developing country, many buildings that are built need to be monitored and inspected. Cracks that form in buildings are a common occurrence. A building component develops cracks whenever the stress in the component exceeds its strength [1]. A crack in a building represents its current structural condition, which can occur frequently if the method of construction is done wrongly or if the building is already timeworn, and it is impossible to avoid.

Cracks in a building usually happen due to the use of low-quality materials, changes in climate or temperature, earthquakes, and more. Thus, there is a demand for the need to inspect and monitor buildings due to inaccessible areas of the crack based on the building’s geometry. The conventional monitoring crack detection of structures has been mainly used in the past [2]. Although visual inspection is the primary way to detect concrete cracks, this method is time consuming, costly, and dangerous for specialists, not to mention that improper environments can also cause evaluation errors [3]. Thus, it is required to study the relationship between distance and crack width to monitor and...
develop an effective way to maintain building inspections regularly [4]. In some cases, it is no longer possible to detect cracks in huge and tall buildings using the conventional method, this is especially important as manual inspections at certain times cannot be done for areas that are inaccessible.

Currently, the development of new technology using UAV application has led to a cost and time-saving way to detect cracks, and in recent years, it has been used for various purposes worldwide [5]. The distance measurement to detect cracks is usually subjective, and UAV technology has been developed in recent years with significant progress for computer vision techniques. The distance can now be obtained in real-time as it is available on the tab that connects to a drone with a high-speed digital camera.

2. Material and Methodology

2.1 Data acquisition
This study was carried out by collecting UAV images at different distance measurements to the crack in a concrete building. The UAV measurement distance was done beginning from 1m from the concrete wall, followed by 2m, 3m, 4m, 5m and finally 6m as shown in Figure 1. A GPS point was established near the study area. About nine (9) control points (CP) of well distributed markers were marked on the concrete wall of the building, which were determined by transferring the coordinates from the established GPS point to each of the CPs using the ground survey method. For the verification process, thirty (30) verification points (VP) were marked surrounding the concrete wall. To obtain accuracy in the assessment process, it was determined using Root Means Square Error (RMSE) value, which must be within the tolerance.

![Figure 1. Position of UAV at each distance](image1)

The conventional measurement uses a crack width gauge/ruler that is designed specifically to measure the width of the crack. This ruler is marked with a range of graded lines and each line is a specified width of crack. The ruler must be positioned over the crack to identify which line is of a similar width to the crack as shown in Figure 2. Different positions and different sizes of cracks in the study area were identified and measured.

![Figure 2. Manual Crack Measurement](image2)
2.2. Methodology
The preliminary UAV image process involves aligning photos, geo-referencing, dense point cloud, mesh, and texture in the Agisoft software. In this process, the default parameter was maintained, but only the quality of the image was changed to the ‘High’ setting. The high setting was required as high-quality images are needed to detect the smallest possible crack at a certain distance. The depth filtering of the dense point cloud was set to moderate while the mesh was created from the dense point cloud created earlier. Face count and polygon count were set to high for a detailed result of the crack surface. For the texture, the DEM and orthomosaic applied the default setting. The error in meter and pixel obtained from geo-referencing the images was within sub-meter accuracy.

The observation of the crack using digital measurement was carried out by an algorithm in the Digimizer software. [6] mentioned that the edge detection algorithm (EDA) examines the crack by using the angle $\alpha$, the absolute value of the difference between the perpendicular angle (90 degrees) and the angle $\beta$, is compared to a threshold angle, $\theta$, which is set 15° as it is used in the previous study where it also mentioned that if $\alpha$ is greater than $\theta$, then the program will color the crack accordingly. If $\alpha < \theta$, then uncracked and if $\alpha \geq \theta$, then cracked. The formula below is used in detecting the crack:

$$\alpha = 90 - |\beta|$$  \hspace{1cm} (1)

Where:
$\alpha$ is the difference between the perpendicular angle (90 degrees) and the angle $\beta$.
$\beta$ is an angle between the vertical axis and the normal of the face associated with a crack region.
$\theta$ is a threshold angle.

Using the UAV image, the generation of texture was used in the crack algorithm to detect the crack using the Digimizer software where the EDA was chosen to enhance the crack on the wall. Binarization was applied as its function is to detect the crack. In this process, the histogram can be adjusted to enhance the crack area which results in an inverted image to a black and white color. Meanwhile, noise reduction was used to reduce the noises on the wall due to the texture of the wall itself and purposely enhance the crack features. Finally, the crack was detected and measured.

3. Result and Analysis

3.1 Crack width measurement
This section is an overview of the result and analysis of the study from the results of data collection to the results of the data processing. The difference between actual and digital measurement of crack is discussed. In the qualitative result, the nearest distance identified all the types of cracks but at the farthest distance, it identified only the medium and wide type of crack; however, hairline and narrow types of crack can be visually (manually) seen. From the quantitative result, the accuracy assessment result which was analyzed was proven to indicate the accuracy of the crack detected at a certain distance where the crack was observable and identified. All the RMSE $x$, $y$ and $z$ were below the allowable tolerance which is acceptable. The accuracy of the UAV image for detecting cracks at different distances was analyzed, where the hairline crack can be detected at the 3m distance, narrow at 5mm distance, medium at 6-meter distance, and wide types of crack at 10mm distance.

| Crack Comparator |
|-------------------|
| Crack Type        | Crack Width (mm) |
| Hairline          | 0.05 – 0.10      |
| Narrow            | 0.15 – 0.30      |
| Medium            | 0.35 – 1.00      |
| Wide              | 1.25 – 3.50      |

Table 1. Crack Width Measurement Classification
Table 1 shows the crack width measurement classification. It is divided into four types which are hairline, narrow, medium, and wide. The classification of the crack follows the crack comparator guidelines from Jabatan Kerja Raya (JKR). From this study, all types of crack widths were found on the concrete wall. The color shows the destructive level of the crack, which indicates the condition of the building.

Table 2. Actual Crack Measurement

| No. | Actual Crack Measurement (mm) | Crack type |
|-----|-----------------------------|------------|
| 1   | 1.50                        | Wide       |
| 2   | 1.00                        | Medium     |
| 3   | 0.80                        | Medium     |
| 4   | 0.30                        | Narrow     |
| 5   | 0.30                        | Narrow     |
| 6   | 0.25                        | Narrow     |
| 7   | 0.20                        | Narrow     |
| 8   | 0.10                        | Hairline   |
| 9   | 0.10                        | Hairline   |
| 10  | 0.05                        | Hairline   |
| 11  | 0.05                        | Hairline   |

As shown in Table 2, a total of 11 cracks were detected from the hairline until wide cracks. Most of the detected cracks at the study area were narrow and hairline cracks, with widths starting from 0.05mm until 0.030mm for the actual crack measurement. The wide width crack detected was at 1.5mm while the medium cracks were at 0.8mm until 1.00mm.

Table 3 shows the actual crack measurement using a crack ruler compared to the digital crack measurement by using EDA in the Digimizer measurement. From the measurement, the difference obtained was between 0.05mm until 0.01mm. The difference from the actual against digital measurement for all cracks should not exceed 0.1mm [7; 3; and 4] when detecting cracks using the automatic crack detection method. Thus, this result shows that automatic detection using the EDA method from the UAV image is acceptable for crack detection purposes.

Table 3. Actual and Digital Crack Measurement

| No. | Actual Crack Measurement (mm) | Digital Crack Measurement (mm) | Difference between Actual and Digital (mm) |
|-----|-------------------------------|--------------------------------|------------------------------------------|
| 1   | 1.50                          | 1.45                           | 0.05                                     |
| 2   | 1.00                          | 0.96                           | 0.04                                     |
| 3   | 0.80                          | 0.77                           | 0.03                                     |
| 4   | 0.30                          | 0.29                           | 0.01                                     |
| 5   | 0.30                          | 0.27                           | 0.03                                     |
| 6   | 0.25                          | 0.26                           | 0.01                                     |
| 7   | 0.20                          | 0.17                           | 0.03                                     |
| 8   | 0.10                          | 0.14                           | 0.04                                     |
| 9   | 0.10                          | 0.11                           | 0.01                                     |
| 10  | 0.05                          | 0.04                           | 0.01                                     |
| 11  | 0.05                          | 0.03                           | 0.02                                     |
3.2 Qualitative and quantitative analysis

Table 4 shows the quantitative measurement for each type of crack at various distance measurements and at different accuracy [8]. The horizontal tolerance accuracy of RMSE, and RMSE, were 0.038m, while it was 0.053m for RMSE. The accuracy of high, low, and medium was reflected on the RMSE value. The closest to the tolerance value was set as high and medium, while below acceptable value was set as low accuracy.

The visibility of the crack was analyzed based on the different distances. Hairline, narrow, medium, and wide types of cracks were visible at 1m until 3m at a high accuracy of 0.023m for 1m distance, medium accuracy of 0.031m for 2m, and 0.034m for 3m. Every crack width at 4m distance was limited to detect narrow, medium and wide types of cracks at medium accuracy of 0.040m, whereas 5m distance only detected medium and wide types of cracks at low accuracy which is at 0.091m. [5] found that medium cracks can be detected until 7.5m, but in this study, it can only be detected at 6m distance for medium and wide width but at low accuracy.

| Distance (m) | Hairline | Narrow | Medium | Wide | High | Medium | Low | RMSE (m) |
|-------------|----------|--------|--------|------|------|--------|-----|----------|
| 1           | /        | /      | /      | /    | /    | /      | /   | 0.023    |
| 2           | /        | /      | /      | /    | /    | /      | /   | 0.031    |
| 3           | /        | /      | /      | /    | /    | /      | /   | 0.034    |
| 4           | X        | /      | /      | /    | /    | /      | /   | 0.040    |
| 5           | X        | /      | /      | /    | /    | /      | /   | 0.091    |
| 6           | X        | X      | /      | /    | /    | /      | /   | 0.270    |

| Distance (m) | Hairline | Narrow | Medium | Wide |
|-------------|----------|--------|--------|------|
| 1           |          |        |        |      |
| 2           |          |        |        |      |
Table 5 shows the complete crack measurement starting from 1m until 6m distance for hairline, narrow, medium, and wide identification. It can be concluded that hairline cracks are visible up to a distance of 4 meters, but quantitatively, hairline cracks are visible at a distance of 3 meters. Narrow, medium, and wide cracks are visible up to 6m as quantitatively shown. The results were different where the narrow type can only visible up to distance of 6 meter as the accuracy obtained shows the precision of the identified crack. As mentioned by [9], high quality and high-resolution images can visually identify a 0.3mm crack up to distance of 10m but this could only achieved by images with sufficient sharpness and good exposure as well as the lowest possible image noise.

### 3.3 Maximum distance for crack detection

Table 6 shows the maximum distance for each type of crack. As it was analyzed qualitatively and quantitatively, the hairline crack can be seen from up to 3 meters with high accuracy, narrow crack can be seen until 5 meters with medium accuracy, while medium and wide cracks are identifiable at 6 meters with low accuracy.
The low accuracy for wide and medium cracks is visible at all distances, but medium crack is visible up to 6m and the rest may be false detection or is less accurate. The distance is suitable for the types of cracks mentioned, which is useful for researchers who investigate cracks on concrete buildings using this distance. Certain cracks have their limit in crack detection on the wall. In this study, it can be concluded that accuracy plays an important role in determining crack detection where without proper or fixed value of accuracy, the crack may be falsely detected. It is important to know the suitable distance for detecting cracks as the same distance may be used for subsequent building inspections; researchers may thus use this maximum distance result for certain cracks in order to recognize crack.

4. Conclusion

Overall, this study provides the capability of the UAV image to detect cracks at different distances. Its capability is to access the accuracy of an image in detecting cracks at different distances. Also, the suitable distance for detecting cracks from the wall was obtained and the edge detection algorithm was performed. The accuracy was divided into three parts which are high, medium, and low ranges. Quantitatively, these four types of cracks were visible at 1m and 2m and 3m at high and medium accuracy respectively, whereas at a distance of 4m, narrow, medium and wide crack were detected at medium accuracy, and at a distance of 5m and 6m, medium and wide cracks were detected at low accuracy. It can be concluded that hairline cracks are visible up to a distance of 4 meters, however, quantitatively, the hairline crack is visible at a distance of 3 meters. Narrow, medium, and wide cracks were visible up to a distance of 6 meters, however, quantitatively, the result differs where the narrow type can only be visible up to a distance of 6 meters. Therefore, accuracy assessment is essential in determining the suitable distance from the crack where sometimes, the visible crack may be noises or false detection.

References

[1] Noh, Y., Koo, D., Kang, Y. M., Park, D. G., & Lee, D. H. (2017). Automatic crack detection on concrete images using segmentation via fuzzy C-means clustering. *Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology, ICASI 2017, 877–880*. https://doi.org/10.1109/ICASI.2017.7988574F

[2] Mohan, A., & Poobal, S. (2017). Crack detection using image processing: A critical review and analysis. *Alexandria Engineering Journal*. https://doi.org/10.1016/j.aej.2017.01.020

[3] Kim, H., Sim, S. H., & Cho, S. (2015). Unmanned Aerial Vehicle ( UAV ) -powered Concrete Crack Detection based on Digital Image Processing. 6th International Conference on Advances in Experimental Structural Engineering & 11th International Workshop on Advanced Smart Materials and Smart Structures Technology, August 1-2, 2015, University of Illinois, Urbana-Champaign, United States.

[4] Shuai, C., Wang, H., Zhang, G., Kou, Z., & Zhang, W. (2017). Power Lines Extraction and Distance Measurement from Binocular Aerial Images for Power Lines Inspection Using UAV, 69–74. https://doi.org/10.1109/IHMSC.2017.131

[5] Kim, J., Kim, S., Park, J., & Nam, J. (2015). Development of Crack Detection System with Unmanned Aerial Vehicles and Digital Image Processing. *Advances in Structure Engineering and Mechanics*.

[6] Zheng, P. (n.d.) (2014). Crack Detection and Measurement Utilizing Image-Based Reconstruction.

[7] Ellenberg, A., Kontos, A., Bartoli, I., & Pradhan, A. (2014). Masonry Crack Detection Application of an Unmanned Aerial Vehicle. *Computing In Civil and Building Engineering, 1788–1795*. https://doi.org/10.1061/9780784413616.222

[8] ASPRS Positional Accuracy Standards for Digital Geospatial Data. (2015). *Photogrammetric Engineering & Remote Sensing*, 81(3), 1–26. https://doi.org/10.14358/PERS.81.3.A1-A26

Abdel
[9] ASPRS Positional Accuracy Standards for Digital Geospatial Data. (2015). Photogrammetric Engineering & Remote Sensing, 81(3), 1–26. https://doi.org/10.14358/PERS.81.3.A1-A26 Abdal