

Application of Image Processing Technology to Crack Behaviour Monitoring

Okayama University Student Member ○BONEY Afia

Okayama University Regular Member NISHIYAMA, Satoshi

INTRODUCTION

Japan's geographical location and geological formation gives the country its unique features. As a result of tectonic activities millions of years ago, Japan is currently a very mountainous country with approximately three-fourths of landmass being occupied by mountains. Therefore, numerous civil engineering structures have been built on rock slopes. Currently, there are about 720, 000 road bridges and 11, 000 tunnels in Japan [1]. As of March 2019, the number of bridges more than 50 years old was 27% and in March 2029, that would increase to 52%. These structures are visually inspected once in a five-year interval by experienced individuals. However, in recent years, the number of workers in the construction industry has not increased, and with budget constraints, the problem is magnified. In addition, since these inspections rely on personnel, judgement is subjective and prone to human errors. Furthermore, the conventional method which uses a crack scale is timely, costly, and unreproducible. Therefore, in keeping with the "2040 Vision for road in Japan" [2], utilising methods that employ automation and reduce labour cost for inspection and diagnosis is recommended to extend the life of these infrastructures.

There has been increased research using image processing and deep learning techniques for visual inspection as an alternative to the traditional method, to ensure objectivity, efficiency, and more automation. Digital photogrammetry has shown it can solve these problems and digital cameras have proven that they can produce quality images, even at distances of more than 10m for crack width measurement [3]. This research proposes a photogrammetric method that assesses the quality and accuracy of crack width measurement, using reflective targets and digital images captured by the smartphone, comparing the results with a

professional digital camera as a reference. According to Statista Research Department, the number of smartphone users in Japan, in 2022, was 107 million (more than 85% of the population), and it is forecast to surpass 115 million users by 2027 (i.e., 94%). In the scientific field, the use of smartphones for research has been gaining interest due to the high-resolution, high-speed CMOS image sensors, high computational capacities, graphic processing units (GPUs), data storage and many more attractive features. Nowadays, smartphones are equipped with cameras that have the potential to capture comparable high-quality images as that of a digital camera. However, until now, there is little research on the use of smartphones in crack width measurement. With the increase in smartphone usage globally, it is worth exploring research opportunities for civil engineering structures.

PRINCIPLE OF CRACK MEASUREMENT

In this research, the cracks are measured by capturing a digital image of two targets. The reflective target, made from reflective, glass-beads, serves as a reference scale since the four white circles are precisely placed. The use of this target determines the unknown parameters from known coordinates. First, the targets are arbitrarily placed on either side of the crack and the photo is taken. The two-dimensional centre of gravity of one of the circles will be calculated, then the perspective projection applied, thereby allowing any angle to be captured. The crack displacement will be the distance between the two targets.

For this experiment, to determine the centre of gravity of the circles on the target, the brightness of the distribution of the circles was applied to detect the two-dimensional coordinates of the centroids, as was also employed by Hirota [3]. The target is separated into white and black areas through binarization by a threshold of intensity value. In this

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700-8530 Okayama, Kita-ku, Tsushimanaka, 1-1-1, Okayama University

method, the white area of the target is set to 255 (RGB colour code) levels of brightness as the threshold while the black portion is set to 0. If the brightness is above the threshold, the following equation, cited and summarized from Hirota [3] was used.

$$\mathbf{x} = \mathbf{x}_0 + \mathbf{a}_x \frac{\sum_{i=1}^n \sum_{j=1}^m (q(i,j) \times x_{ij})}{\sum_{i=1}^n \sum_{j=1}^m q(i,j)} \quad \text{Eqn 1}$$

$$\mathbf{y} = \mathbf{y}_0 + \mathbf{a}_y \frac{\sum_{i=1}^n \sum_{j=1}^m (q(i,j) \times y_{ij})}{\sum_{i=1}^n \sum_{j=1}^m q(i,j)} \quad \text{Eqn 2}$$

Where \mathbf{x} and \mathbf{y} are the centre of gravity coordinates, \mathbf{x}_0 and \mathbf{y}_0 are the origin of the centre of gravity calculation range, \mathbf{a}_x and \mathbf{a}_y are the number of pixels and $q(i,j)$ is the brightness of the pixel (i,j) .

The coordinates of the four circles on the target are used as a reference to execute the projective transformation. It will transform the camera coordinates into the object space coordinate system. Additionally, the collinearity condition was employed in this research. Collinearity condition is the condition where the perspective centre, which can be any object point, and its corresponding image point all lie in a straight line in three-dimensional space. As highlighted by the red line in Figure 1, L, a, and A all lie in straight line.

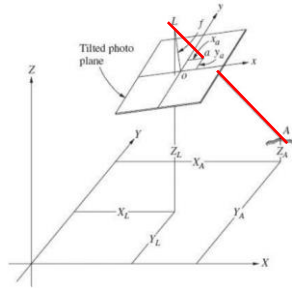


Figure 1: Collinearity Condition concept [6]

Two equations can be used to express the collinearity condition for any point on a photo.

$$\mathbf{x}_a = \mathbf{x}_0 - \mathbf{f} \frac{\begin{bmatrix} m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L) \\ m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L) \end{bmatrix}}{\begin{bmatrix} m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L) \end{bmatrix}} \quad \text{Eqn 1}$$

$$\mathbf{y}_a = \mathbf{y}_0 - \mathbf{f} \frac{\begin{bmatrix} m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L) \\ m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L) \end{bmatrix}}{\begin{bmatrix} m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L) \end{bmatrix}} \quad \text{Eqn 2}$$

Where \mathbf{x}_a and \mathbf{y}_a are the photo coordinates of image point a, $X_A Y_A Z_A$ are object space coordinates of the point A, $X_L Y_L Z_L$ are object space coordinates at a point in object space, f is the focal length of the camera, \mathbf{x}_0 and \mathbf{y}_0 are the principal point (usually known), \mathbf{m} 's are the elements of three rotation angles [6].

IMAGE ACQUISITION

The smartphone used in this research was the iPhone14 Pro and the DSLR camera used was the Canon EOS KissX7 with lens SIGMA 18-250mm F3.5-6.3 DC Macro OS HSM. Figure 2 shows the cameras used. The specifications of each device are listed in Table 1.



Figure 2: A. Image of the iPhone 14 Pro with an annotated diagram B. Image of Canon EOS Kiss X7

Table 1: Specifications of each device

	Smartphone	Camera
Brand & Model	iPhone 14 Pro	Canon Kiss X7
Focal Length	24, 13, 77mm	18-250mm
Sensor size	9.8 x 7.3	22.3 x 14.9
Pixel size	2.44 μm	4.3 μm
Year	2022	2013

METHODOLOGY

To investigate the crack displacement, tests were conducted in two different sites. First, a laboratory experiment was performed to measure the displacement and determine the accuracy of this method, then the same principle was applied to a retaining wall.

Laboratory Test

The apparatus was set up as shown in Figure 3. A micrometre was affixed to one 55mm-target, while the other 55mm-target was permanently attached to the surface. This micrometre would simulate the displacement. A torch light was used as a source of additional light. The photos were taken in two formats, raw and compressed. The mode of each camera was set to autofocus due to the quantity of photos required. To determine the influence the shooting distance and shooting angle have on the accuracy, images were taken at various angles and distances as shown in Table 2 below. The micrometre displacement is in 0.2mm increments from 0.2 to 1.0. Five photos were taken at each distance and angle varied. During the analysis, the average of the five measurements between the targets would be used as the distance between the targets and thereafter, the

displacement calculated. Approximately 526 images were captured on both cameras. The collected images were transferred to a PC to be processed. Using a software called Image Measure© the distance between the two targets was calculated.

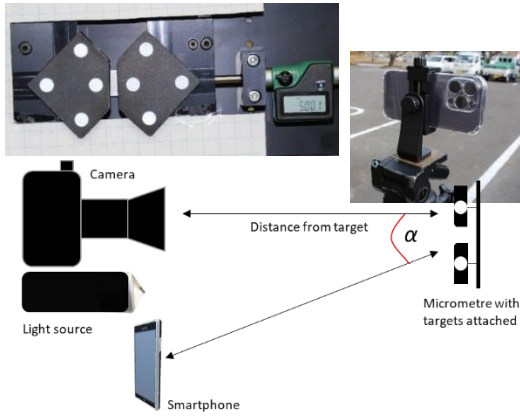


Figure 3: Set up of experimental apparatus

Table 2: Parameters used in the experiment

Shooting Distance	Canon Kiss X7 Focal Length	iPhone 14 Pro Focal Length	Angles used
1m	18mm	7mm	22°, 45° and 0°
3m	51mm		
5m			
7,10,15,18m	250mm	9mm	

EVALUATION OF ACCURACY

In this research, two types of accuracy were defined: internal and external. External accuracy (EA) is given by the following equation:

$$External\ Accuracy = \sqrt{\frac{\sum(measured\ value - true\ value)^2}{n}}$$

Where the measured value is the calculated displacement, and the true value is the displacement of the micrometre. Therefore, the difference between them was determined to be the error. n is the number of displacements of the micrometre. The internal accuracy (IA) is the equivalent of the standard deviation of the estimated error.

$$Internal\ Accuracy = \sqrt{\frac{\sum(measured\ value - average\ of\ n\ measured\ values)^2}{n}}$$

Both result values should be small, which would suggest a higher precision of the measurement.

In the first instance, the influence of the shooting distance was investigated. Figure 4 shows that as the distance is increased, the accuracy decreased for both devices. However, the DSLR performed better than the smartphone. Except for 1m for the smartphone, this method measured

displacement with the accuracy and precision of less than 0.2mm. Distances 10m-18m also decreased in accuracy even with increased focal length. Table 3 compares the results of both devices as the distance is increased.

Table 3: Comparison of results as the distance is increased

	Distance from target	Short Distances			
		1m	3m	5m	7m
Canon Kiss X7	EA (mm)	0.04	0.04	0.08	0.07
	IA (mm)	0.04	0.03	0.07	0.07
iPhone 14 Pro	EA (mm)	0.28	0.11	0.13	0.20
	IA (mm)	0.28	0.09	0.10	0.18

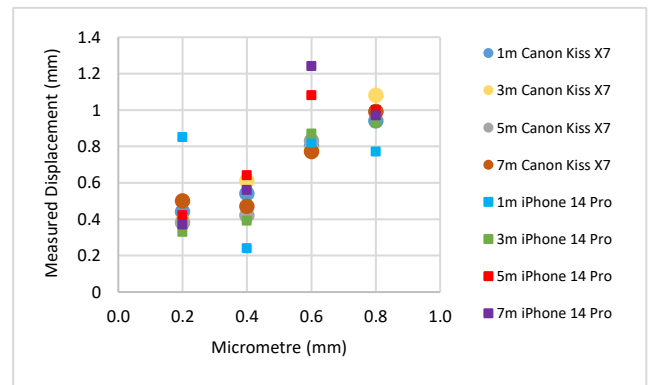


Figure 4: Comparison of the measured displacement

In addition to varying the distance, the shooting angle was also changed as shown in Figure 5. As the angle was increased, the accuracy decreased. At 45° on the DSLR, accuracy improves, which should be examined in the future. When the DSLR was used, the accuracy measured less than or equal to 0.12mm. On the other hand, the smartphone error increased drastically, reaching as high as 0.91mm.

Table 4: Comparison of results as the angle is increased

	Angle (°)	0	22	45
	Canon Kiss X7	EA (mm)	0.07	0.12
IA (mm)		0.07	0.12	0.06
iPhone 14 Pro	EA (mm)	0.15	0.44	0.91
	IA (mm)	0.15	0.42	0.91

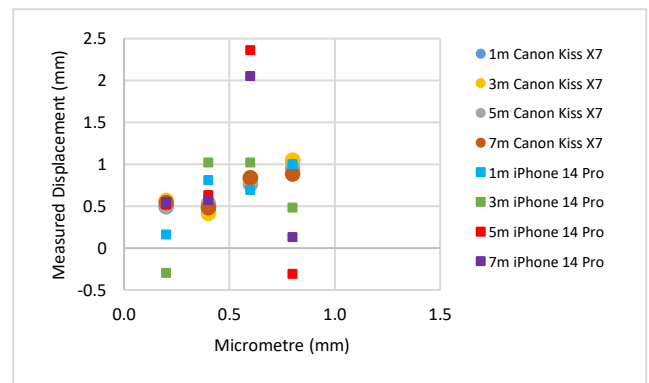


Figure 5: Comparison of the measured displacement

On-site verification

A 30–40-year-old retaining wall at a busy intersection in Uno district Tamano City was chosen as the area to verify the findings. Tamano City, is a small, coastal town, located to the southernmost tip of Okayama Pref. The city is approximately 60% mountains making the topography steep and rugged. The city is susceptibility to sediment disasters and landslides caused by heavy rainfall and typhoons. To prevent future hazards from occurring, it is necessary to monitor such a structure. For this research, images were taken over three consecutive months to obtain the displacements of the crack width. The location of the retaining wall is shown in Figure 6.



Figure 6: A. Retaining wall with an inset image of the target at position 2. B. Taking a photo from an arbitrary position

Figure 7 shows the measured displacement at position 4. At 1m and 2m, both devices produced comparable results. As the distance is increased to 20m, the results for the smartphone are unreliable.

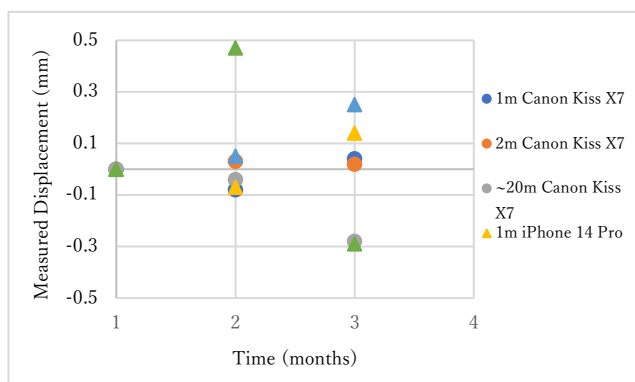


Figure 7: Change of cracks' width at position 4

DISCUSSION

In this research, the gravity of the centre of the target is crucial to determine the threshold value. At short distances or if the target is large, the centre of gravity will result in less movement. On the other hand, when the target appears small or the distance is far, the external and internal errors will increase. Hence, at short distances for both devices, the error is small compared to at long distances.

CONCLUSION

This study aimed to determine the influence of the distance and angle on the accuracy and precision of the crack width taken with a smartphone and a DSLR camera, as a reference. The external and internal accuracy were used to evaluate the systematic and chance error. It was found that an iPhone 14 Pro equipped with a 48MP camera has similar performance as a DSLR in the monitoring of crack width measurement. The smartphone produced comparable results to the DSLR at short distances (1m–7m). However, at long distances, the smartphone is not recommended for use with a 55mm x 55mm target. However, with the ongoing development of smartphone technologies, it is possible to increase the accuracy and overcome challenges encountered in the civil engineering field.

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