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Improved digital photogrammetry technique for crack monitoring

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ABSTRACT

Inspections to evaluate the safety, durability, and service life of aging infrastructure play an important role in determining the countermeasures that need to be taken, such as reinforcement, repair, and reconstruction. In infrastructure containing concrete, such as bridges and tunnels, crack widths and patterns on surfaces are two of the most important signs used to estimate durability. Current conventional techniques used for this purpose suffer from challenges such as tediousness, subjectivity, and high cost. Consequently, a new measurement technique that overcomes these challenges while measuring crack displacement with high accuracy and precision in aging civil engineering structures is needed. In this paper, we proposed a technique for measuring crack displacement using a digital camera image. In the proposed technique, reflective targets are established around both sides of a crack as gauges, and subsequent digital camera images of the targets are subjected to image processing to determine the displacements of the targets. These displacements can be measured using images captured from any arbitrary camera position. The results of experiments conducted to verify the efficacy of the proposed method show that crack displacements of less than 0.10 mm can be measured with high accuracy and precision using digital images captured at a distance of 10.0 m from the target, while less than 0.20 mm changes in the tensile displacement of the crack can be measured from an image captured at 25.0 m from the crack. Measurement results obtained from a tunnel are also presented to show that cracks in the walls of an actual tunnel can be identified through simple measurements. These measurements, taken over a period of one year, indicate that the tendency of crack displacement and slide movements are in close agreement.

1. Introduction

Much of the infrastructure in Japan was developed during the period of rapid economic growth in the 1960s. Some of the structures involved are now more than 50 years old; consequently, it is essential that they be monitored in order to ensure that they are safe [1,2]. Inspections to evaluate the durability and service life of such infrastructure play an important role in determining the countermeasures that need to be taken, such as reinforcement, repair, and reconstruction. In infrastructure containing concrete, such as bridges and tunnels, crack widths and patterns on surfaces are two of the most important signs used to estimate their durability. To measure the change in crack width and to prevent resultant damage, it is necessary to establish techniques for monitoring the crack behavior (e.g., [3,4]). Most existing approaches in this area are hand-sketch based, and crack openings are often evaluated using measuring magnifiers or crack width rulers; therefore, conventional measurement methods are manual, which may lead to nonobjective evaluation. Fiber optic sensors are also being used for crack monitoring. This technique does not utilize visual inspection and achieves measurements with accuracy similar to the standard strain gauges and extensometers; however, the cost of the data readout equipment used in applications coupled with installation and connection of the acquisition systems is very high (e.g., [5,6]). In contrast to wired systems, wireless systems require no cables for data transfer and are known for their low cost of deployment; however, their lifetime is limited by their battery-operated sensing devices (e.g., [7,8]).

This paper proposes a new crack monitoring measurement technique based on digital image processing and photogrammetry that overcomes the challenges outlined above. A variety of digital image processing technology based measurement systems have been developed. The majority of these systems recognize the number of the pixels in a crack image reflected in the image as the crack width, and utilize image processing techniques such as binarization processing to facilitate counting of the number of the pixels in the crack image [9–13]. However, because the pixels of the crack

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image reflected in the image vary significantly depending on the photographing conditions, especially lighting, it is difficult to measure the change in crack width with high accuracy in the actual field. Moreover, photogrammetry based measurement systems are not very popularity because it utilizes a complicated process in which images need to be taken from various camera positions [14–17].

In our proposed technique, reflective targets are established as gauges at measurement points along both sides of a crack, and the two-dimensional displacement of the crack—tensile and shear displacement—is calculated based on the coordinates of these targets using only one image, captured from any arbitrary position.

(1) Measurement can be performed using only a digital camera, reflective targets, and a PC, keeping costs very low, as low as that of the conventional photogrammetry method. However, unlike the conventional photogrammetry method, measurement is performed using only one captured image, as opposed to multiple images being required.
(2) The measurement values of the crack width can be calculated independent of the lighting conditions, unlike the conventional image processing method, because the proposed technique recognizes the distances between the circles of the targets as the crack width.

The results of experiments conducted verify the measurement accuracy of the proposed method in its determination of the relation between the distance and the angle of photographic positions from the targets. Further, we present the measurement results for crack displacements in a tunnel damaged by a landslide to demonstrate that the durability of an infrastructure can be identified through simple measurements.

2. Principle of crack measurement

This section explains the proposed technique and the principle for measuring cracks from digital images. This proposed technique can be used to measure the width of a crack without detecting the crack itself [18].

2.1. Measurement process

The width of a crack is measured as follows:

(1) Reflective targets are installed around the crack as gauges, as shown in Fig. 1 [19]. These targets are designed with four glass beads arranged in circles to induce the strong diffuse reflection of incident light. The size of the target changes according to the distance between the photographic position and the target. The four circles on one target is used for markers for perspective projection that is explained later, and one pair of circles on both sides of the crack is used for measuring the change in crack width. The distance between one pair of circles on both sides of the crack is measured, with the change in the distance indicating the displacement.
(2) A digital image of the targets is captured from an arbitrary camera position and angle. The captured digital image is then converted to one facing the target via perspective projection [20].
(3) The two-dimensional coordinate of the centroids of the circles in the image are measured via image processing.
(4) The distances between the circles of the targets on both sides of the crack indicate the tensile and shear displacements.

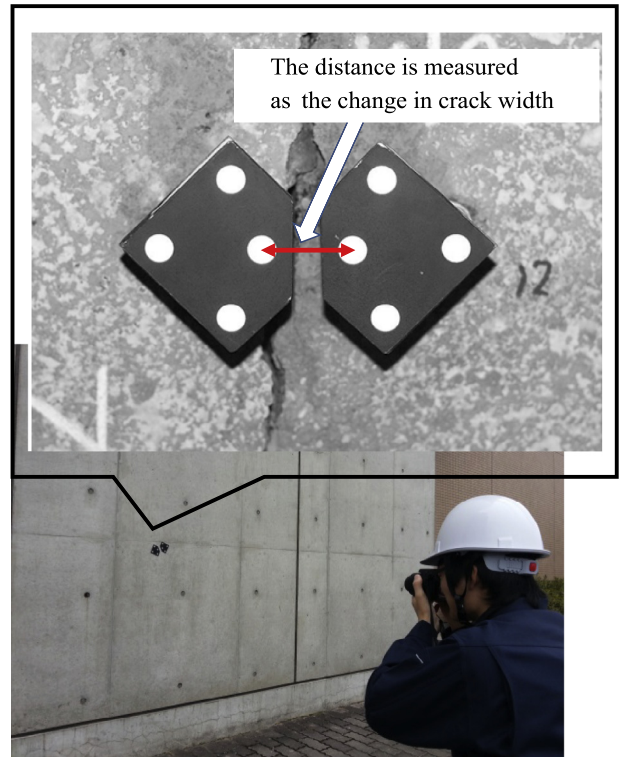

Fig. 1. Capturing a digital image of the targets from an arbitrary position. Reflective targets are established on both sides of a crack.

This measurement procedure has the following characteristics:

(1). It involves only photographs and eliminates the need for human expertise to improve accuracy, as required in conventional measurement techniques.
(2). It requires only a digital camera, targets, and a PC, which reduces cost.

2.2. Basic principles of target coordinate measurement

Image processing is used to simplify identification of the centroids of circles in the images. The measurement accuracy/precision of the system strongly depends on that of the two-dimensional coordinates of the centroids of the circles on the targets as measurement points [21]. Therefore, to improve this two-dimensional measurement accuracy/precision, reflective targets arranged in circles are established at the measurement points. The glass beads can induce the strong diffuse reflection of light. The digital imageries are categorized into gauge imageries in white and other areas in black through binarization using a certain threshold intensity that is less than half the maximum value. Fig. 2 illustrates the distribution of the intensity distribution of the circle. The multiple lines in the right figure represent various examples of the intensity distribution displayed in a two-dimensional section, and the red line is an example of the threshold intensity for binarization. The white areas are calculated based on a binary image acquired by the binarization processing, but the diameter of the circle should be fairly large, at least 20 pixels or bigger with a uniform pattern by adjusting the photographing condition.

The two-dimensional coordinates of the centroids are obtained by calculating the center of gravity of the white areas in each circle to obtain the centroid even in an elliptical shape. Assuming that the x- and y-coordinates are $x = 1–n$ and $y = 1–m$ in the image coordinate system, the coordinates (x, y) of the gauge imageries are