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Development of crack diagnosis and quantification algorithm based on the 2D images acquired by Unmanned Aerial Vehicle (UAV)

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ABSTRACT

In this paper, we developed techniques to identify and quantify the damage to bridges based on images obtained by the unmanned aerial vehicle (UAV). Currently, the bridge inspection is carried out through a visual inspection by manpower but has limitations on the accuracy of the inspection and accessibility of the bridge. Thus, the method of bridge inspection using unmanned inspection equipment is expected to complement the limitations of these existing methods and replace them altogether. The process of detecting and quantifying damage is usually three steps, the first step was to acquire images using UAV and second step was image processing using MATLAB, the third step was to quantify and express damage on original images. Performances of the technique were evaluated through lab-test and field test. The width of the cracks in the steel and concrete bridge deck surface and pylon was quantified in units of 100μm. The non-contact bridge damage detection technology proposed in this study can be applied to the actual bridge inspection field and it is expected that the economic and technical efficiency will be high.

1. INTRODUCTION

Recently, the importance of safety and maintenance has been emphasized due to the recent construction of large bridges and the deterioration of existing bridges. However, most of the maintenance work is dependent on the manpower. Moreover, compared with developed countries, the development of the domestic facilities maintenance market is insufficient and the maintenance technician is more needed for the safety of the aging facilities.

Appearance inspection is carried out by inspecting the exterior problems of bridges by using skilled professional manpower, ladder special vehicles, and equipment or by using safety diagnostic devices pre-installed on bridges. Current visual

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inspection methods using special vehicles are also burdensome in terms of economic efficiencies, such as traffic congestion caused by vehicle control and installation of safety equipment to ensure the safety of investigators. Especially in the case of spherical bridges, safety devices for investigators are not installed or insufficient.

The appearance inspection of the bridge by the drone can reduce the cost of bridge safety diagnosis relatively because the use of the input manpower and special equipment is minimized. In particular, periodic shooting by the drone and the situation of the bridge inspection can be recorded, and a database can be used for regular safety inspection of the structure.

In this paper, it covers only the cracks among various apparent damage to the bridge. Cracks in the surface are one of the initial signs of degradation of the structure, which is essential for maintenance, and sustained exposure can cause severe damage to the environment. Particularly, in the case of concrete structure, cracks of 300 micrometers or more are the criteria for evaluating the condition of bridges. In the case of steel structures, cracking itself may cause serious structural damage.

2. Theoretical Background

2.1 Otsu's threholding

The chromaticity value at the boundary between the regions is called the threshold value. One of the threshold calculation methods for calculating the threshold value optimally is the Otsu method. In 1972, Nobuyuki Otsu proposed a threshold calculation method to find the optimum T value by using the variance in class and the variance between classes. In the case of the distribution method in the class, since the dispersion value indicating the degree of the pixel distribution is smaller and the dispersion method between the classes is the inverse of the dispersion in the class, the larger the dispersion value, the better the optimal T value can be obtained.

Intra-class variance is defined as

$$\sigma_w^2 = \omega_0(T)\sigma_0^2(T) + \omega_1(T)\sigma_1^2(T)$$

where ω_0 and ω_1 are the probabilities of the two classes separated by the threshold T, and σ_0^2 and $\sigma_1^2$are variances for these two classes. The probabilities are computed from L histogram:

$$\omega_0(T) = \sum_{i=0}^{T-1} p(i)\,;\ \omega_1(T) = \sum_{i=T}^{L-1} p(i)$$

The class mean value can be calculated as

$$\mu_0(T) = \sum_{i=0}^{T-1} ip(i)\,/\omega_0;\ \mu_1(T) = \sum_{i=T}^{L-1} ip(i)\,/\omega_1$$

And the individual class variances can be obtained using

$$\sigma_0^2 = \sum_{i=0}^{T-1}[i-\mu_0(T)]^2\frac{p(i)}{\omega_0(T)};\ \sigma_0^2 = \sum_{i=T}^{L-1}[i-\mu_1(T)]^2\frac{p(i)}{\omega_1(T)}$$

A number between 0 and 255 should be assigned to T and the corresponding intra-class variances are computed using the above formulas. The value of T corresponding with the maximum intra-class variance is the thresholding value called Otsu's value (Otsu 1979).

2.2 HSV color space

HSV color space is defined with hue, saturation and the value of a color. A hue of color (H) is the pure color resemblance, which is described by a number between 0 and 1, specifying the position of the pure color on the color wheel. The saturation Value (S) of a color stands for how white the color is. For instance, a pure red has the saturation of 1, while the white has the saturation of 0. The value of a color (V) represents the lightness of the 39 color, for instance, a pure black has V value of 0. The cracks showed larger values in the S component of the color image. This characteristic is used to categorize cracks from irrelevant objects that have not been cleared from the image yet (Lins and Givigi 2016).

3. Proposed crack diagnosis algorithm

The process of detecting and quantifying damage usually consists of three steps, the first step was to acquire images through UAV and second step was image processing using MATLAB, the third step was to quantify and express damage on original images (Mohan and Poobal 2017). Considering the general order of diagnosis algorithms, an algorithm for detecting the cracks in the surface (concrete, steel) is proposed and is shown in Fig. 1.

Step 1: Image Acquisition

Generally, the image is captured using the CCD camera mounted on UAVs, and the higher the number of effective pixels, the better the image processing. And then read the video file to extract the frame containing the region of interest area and save it as a JPEG file format.

Step 2: Image pre-processing and post-processing

In the proposed method, the original image was converted to a grayscale image. A median filter was applied to reduce a noise like a stain or blurring on image and to smooth the image. The Otsu's thresholding algorithm is used to convert the intensified edge image to a binary image. In this step, Area thresholding algorithm which is remove the object area less than 150 pixels. Since the shape of the crack is not perpendicular or horizontal, the connected components with the orientation of 0 and 90 degrees were then removed through the orientation based elimination technique. To remove the small noise remaining on the image, the objects with an area less than 50 pixels were eliminated. Finally, using the crack properties in the HSV color space, cracks from other surfaces irregularities such as edges and watermark, stain were separated.

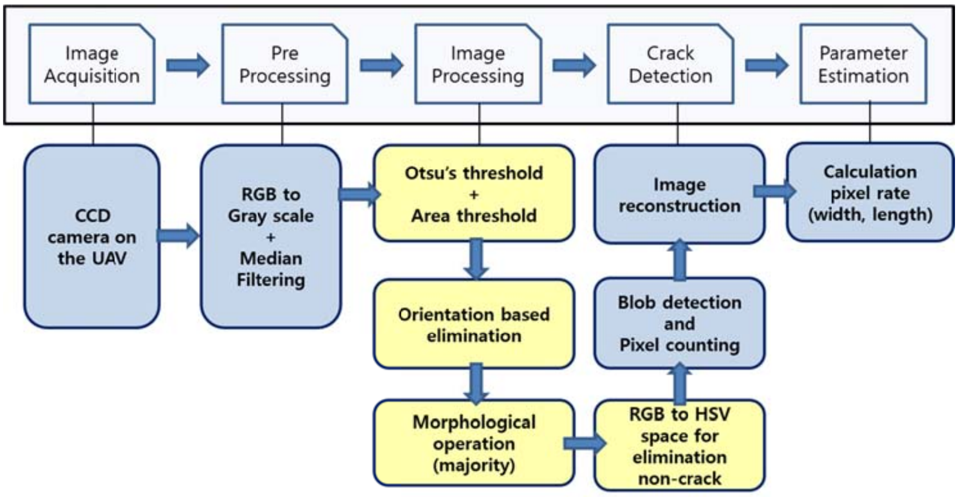

Fig. 1 The proposed crack diagnosis algorithm

<u>Step3: Crack detection and Parameter estimation</u>

The region where the crack is detected is visualized by recombining on the original image. Through the blob detection technique and pixel calculation steps, the number of effective pixels recognized as cracks is calculated, and the width of the crack is quantified using the pre-calculated pixel rate value.

4. Experimental Validation

4.1 Lab-test for validation of the proposed diagnosis algorithm

In this section, a lab test was conducted to verify the crack detection algorithm proposed above. The lab test was performed by installing a CCD camera on a movable jig to simulate the situation on a drone and using a camera to acquire an image of a fatigue cracked steel specimen made using UTM and then applying a crack detection algorithm. Fig. 2 shows a setup for the lab-test.

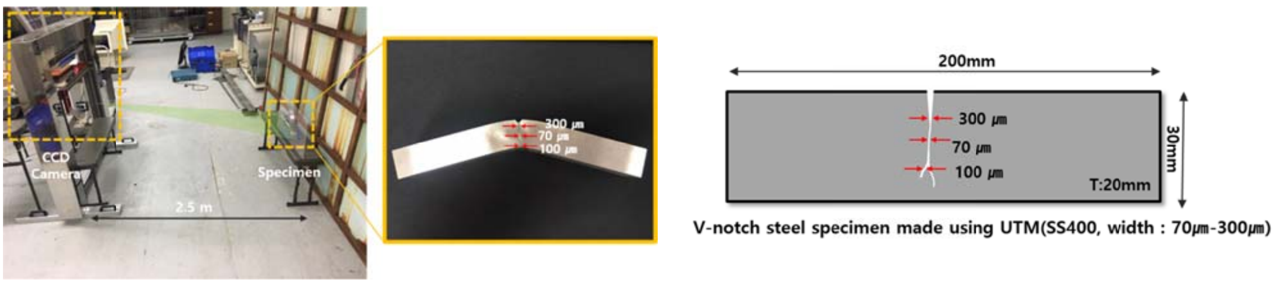

Fig. 2 Setup for the lab-test

The crack detection algorithm was implemented through the MATLAB program. As a result of applying diagnosis algorithm, the cracks of the steel specimens were quantified and showed the error of about 4% as shown in Fig. 3. In the case of crack B, the error of the pixel rate was 13%, which was calculated using the subpixel concept.

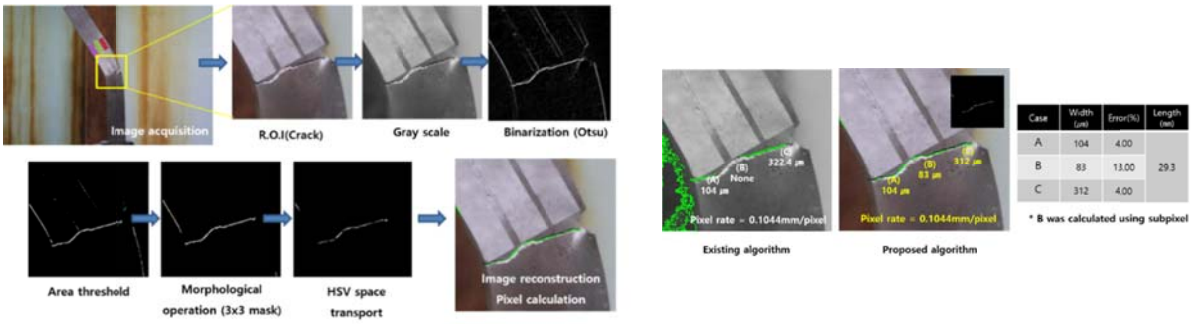

Fig. 3 Steps for application of crack detection algorithm

4.2 Field-test for validation of the proposed diagnosis algorithm

In this chapter, we carried out a visual inspection of the actual bridge with CCD imaging equipment mounted on the UAV. The inspection target is the Deungseon Bridge located in Chuncheon, which is a type of STB and PSCB. The UAV used in this experiment was developed for a professional bridge inspection by Ex-drone and was shown in Figs. 4 and 5. The CCD camera installed on UAVs was HDR-PER 790 V and FDR 3000r, and each of the two different types of cameras was used for the acquisition of various images (see Table 1).

UAV(Ex-drone) CCD Cameras
(L: FDR 3000r, R: HDR-PJ790V)
Fig. 4 CCD cameras mounted on UAV

Fig. 5 Inspection using UAV
(Deungseon Bridge)

Table 1 Specification of CCD Camera

Type	HDR-PJ790V	FDR 3000r
Min. Focus	1m	0.5m
Shutter speed	1/60 (60fps)	1/30 (30fps)
Image size	24.1MP (6544x3680)	8.2MP (3840x2160)
Weight	660g	114g

As shown in Fig. 6, it was possible to calculate the number of pixels in the area detected as a crack, but the pixel rate value could not be calculated because the distance information between the target structure and the UAV could not be obtained. Later, if accurate pixel rate values can be obtained through a method of obtaining the distance between the target structure and the UAV (LiDar sensor, etc.), it is expected that the micro cracks on the surface of the structure can be quantified in units of 100 micrometers.

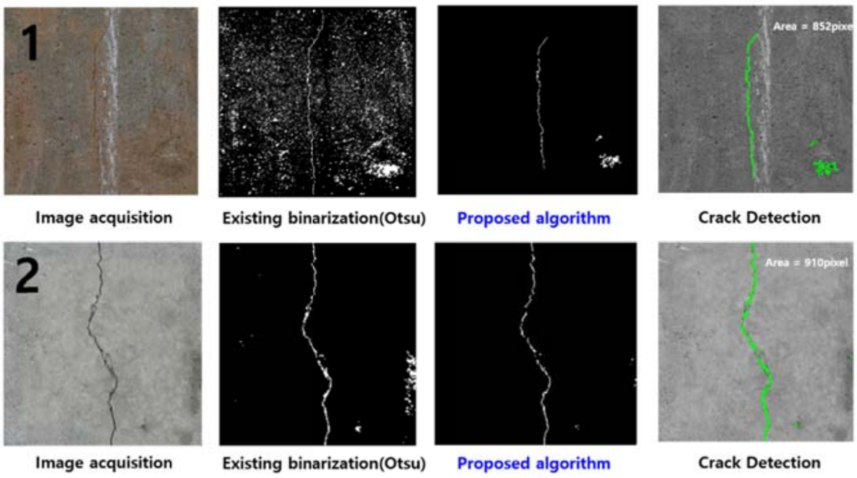

Fig. 6 Results of crack detection in the field test

5. Conclusion

In this paper, we propose an algorithm to detect cracks on the surface of concrete and steel bridges by improving the general crack detection algorithm, Otsu method. Lab-test and field-test were carried out to verify this, and lab-test results were used to quantify cracks in 100-micrometer unit. In field-test, images were acquired using a CCD camera mounted on an actual UAV and analyzed. However, it is not possible to quantify the cracks because the distance between the UAV and the target structure is not obtained. However, it is expected that the crack width can be quantified by using the accurate pixel rate. If the proposed technique is used for actual bridge safety inspection, it is expected that it will be possible to secure the safety of the inspectors and to conduct a more economical and accurate bridge inspection.

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REFERENCES

Otsu, N. (1979), “A threshold selection method from gray-level histograms. IEEE transactions on systems”, *Man, and Cybernetics*, **9**(1), 62-66.

Lins, R.G. and Givigi, S.N. (2016). “Automatic crack detection and measurement based on image analysis”, *IEEE Transactions on Instrumentation and Measurement*, **65**(3), 583-590.

Mohan, A. and Poobal, S. (2017), “Crack detection using image processing: A critical review and analysis”, *Alexandria Engineering Journal*.