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Research Article

A Concrete Crack Inspection Embedded in the Drone-Based System by Using Sub-Pixel Width Estimation and Morphological Component Analysis

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ABSTRACT

Human experts have assured social infrastructure inspections, and recently an automated inspection is expected as an integrated system of the flight vehicle with software algorithms of the image processing. For the submillimeter-width concrete-crack detection, we have introduced Morphological Component Analysis (MCA) to be able to find those positions. Conventional image processing methods work well for thick-width crack detections, while the thin-width crack detection is highly difficult. We successfully demonstrated a concrete crack detection from images through proximity cameras in a specialized multi-copter and MCA-based crack position estimations and the linear regression-based sub-pixel width estimation were integrated together. It will open a new door to engineering in the actual field work, which can be widely applicable for social infrastructure inspections in general.

1. Introduction

For the achievement of the sustainable society, the infrastructure maintenance is an important social demand. An early-stage detection of cracks in the concreate buildings [1], [2], [3], [4], [5] is also an urgent issue as a prospective validation. In the past and present, human experts were truly necessary for the execution of careful inspections, while the inspection is a risky task especially in high places, which requires special cares and huge costs for the safety assurance. In a recent trend, an automated and remote detection method with flying systems, such as a drone has been discussed. In Japan, the national research project "SIP Infrastructure Regional Implementation Support Teams: Promoting Innovation in Regional Infrastructure Maintenance," had promoted from 2014 to 2019, to provide innovative inspection systems in a competitive style of teams organized by academic-industrial partnerships [6]. In a team of the project as a part of academic advancement [7], we had contributed by using Morphological Component Analysis (MCA) [8] for the concrete-crack detection and position estimation by focusing on submillimeter-width crack detections, which are highly difficult for traditional methods. In our project, a concrete crack detection from images through proximity cameras in a specialized multi-copter was the target mission to be able to measure its length and width, because inspection reports require to its chronological record to predict when a crack reaches at an incurable level. In the present study, the sub-pixel estimation method for lengths and widths of concrete cracks was proposed, which fits for the direction of extension of cracks even they were wandering.

The remainder of this paper is organized as follows. After giving brief introduction of our work in section 1, in section 2, the hardware and software systems were explained as the overview of the inspection procedure from the image acquisition to an inspection report. In

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section 3, the proposed method was described and in section 4 experimental results were described, which is followed by conclusion in section 5.

2. Inspection System Design Using a Multicopter

2.1. *Hardware design*

We introduced a multi-copter, or simply drone, which contains high proximity cameras as a part (Figure 1). The video image can be obtained with the same distance L between the camera and the concrete surface.

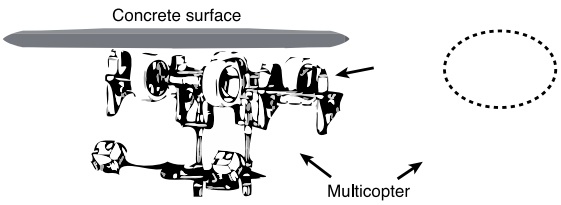


Fig. 1. The multi-copter inspection system with wheels to keep the same distance L between cameras ($C1$ and $C2$) and the monitoring surface (illustrated as a redraw version from [7])

2.2. *Software design*

Obtained images in the form of videos were converted to split snapshots of the target concrete surface (Figure 2). We classified three types by its widths, as large (more than 1mm width; Figure 3 (a)), middle (about 1mm width) and minor cracks (less than 1 mm width; Figure 3 (b)). By using multiple methods with image morphology (IM), anisotropic diffusion filter (AD) and MCA methods were applied to detect them as Dixit and Wagatsuma demonstrated [9], [10]. After the crack position estimation, an accurate gauging is important for a fine inspection report, which was done by human experts normally.

In the present study, we proposed a method for the sub-pixel estimation for length and width measurements of concrete cracks. Since most of cracks are not simply extending straightforward and they are extending in a zig-zag way, it is not easy task but the highly important mission to assure an appropriate measurement.

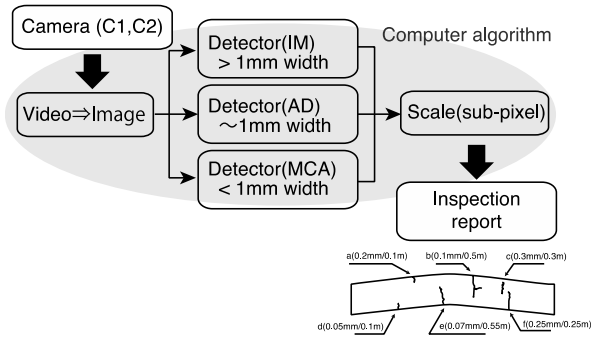
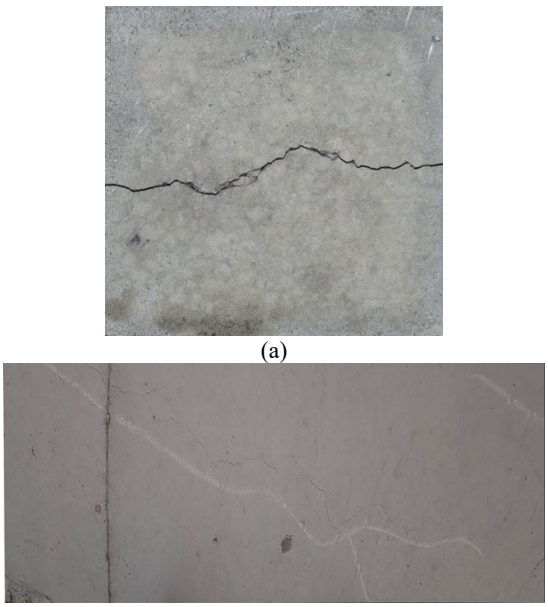


Fig. 2. The whole workflow of the information processing from the image data acquisition to the inspection report.



(a)

(b)

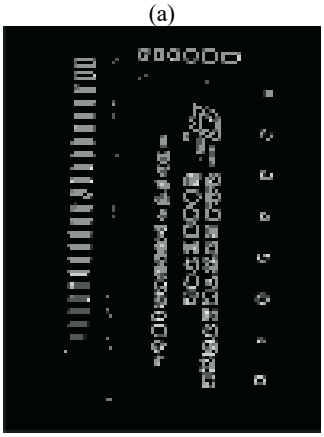
Fig. 3. Example of concrete cracks. (a) larger than 1mm width and (b) less than 1mm width.

3. Proposed Method

In the aim of a fine crack-width estimation, which is expected to perform in the human expert level by using the crack gauge (Figure 4(a)), an edge detection is an inevitable mission for the estimation of the gap, which is defines by high image contrast pixels with black and white colors (Figure 4(b)). Since a crack forms a continuous line structure in the image, a tangential section is required to measure its width (Figure 5). According to such requirements, the sub-pixel estimation method was designed as a procedure (workflow) with following steps:

1) Extraction of a pre-straight line as target
2) Estimation of the tangential angle against the target line (Figure 5 (a))
3) A curve fit to trace the discrete stair-like color difference according to pixel-based representation in the image (Figure. 5 (b) as the ideal data)
4) A transition point detection in the fitted curve to represent the crack in the form of the negative valley of the brightness of colors as the estimated width (Figure5 (b))
5) Plotting of the width and length of the crack at the position of the detected crack for the inspection report (Figure 5 (c))

(a)



(b)

Fig. 4. The traditional crack gauge and a processed result by using AD filter described in Fig. 2 [9], [10].

In the first place, as shown in Figure 5(a), if the measurement is done in a non-tangential direction, counting of pixels on the line reports a wrong width. Each connecting width has a certain length and therefore the width measurement must be done in multiple points along the connecting line as shown in Figure 5(c). In the second place, if the width estimation is executed as the simple counting of pixels with a highlighted color (the white color in the case of Figure 4 (b)), mistakes in calculation will be happing due to the brightness variation depending on external illuminations in the environment. Therefore, a natural gradient must be reconstructed artificially as illustrated in Figure 5(b). In a smooth reconstructed curve from pixels around the gap, a folding point can be measured from the curve, which is the plausible point of the edge of the gap.

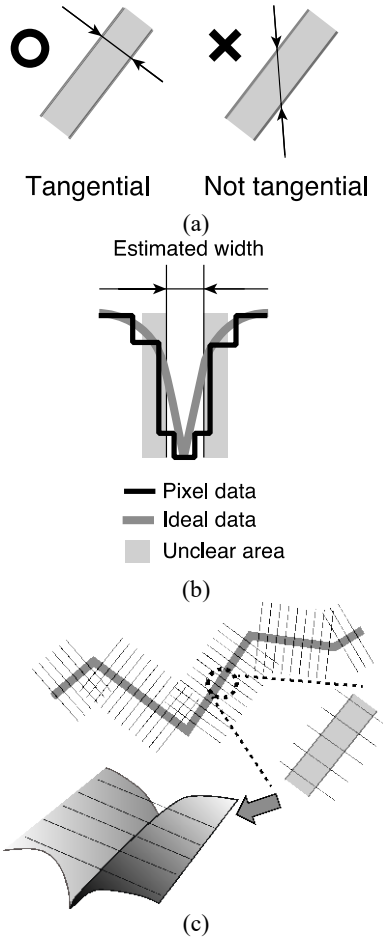
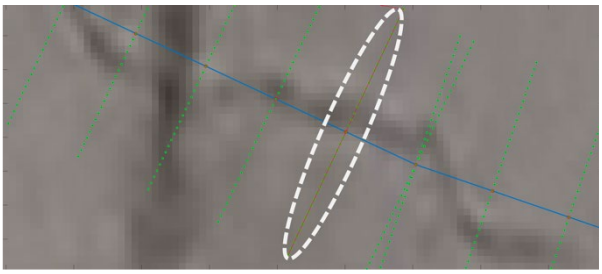


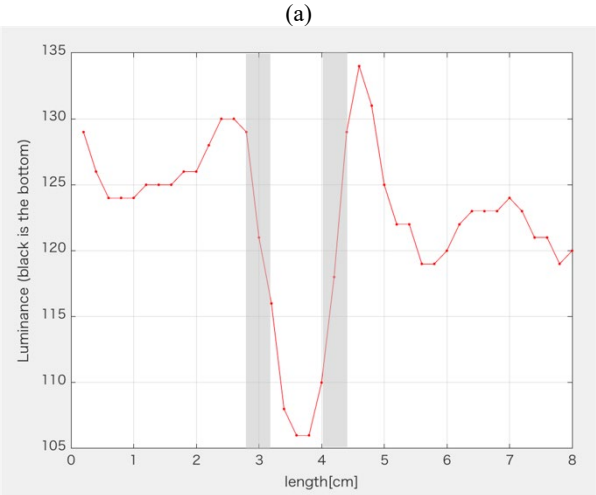
Fig. 5. The proposed sub-pixel width estimation method for an appropriate measurement.

By the integration of those concepts to avoid possible risks to prevent an appropriate and assured measurement, as described in five steps above, the proposed algorithm was implemented in MATLAB to apply to actual images. For example, as shown in Figure 6(a), measurement guidelines (green lines) were mapped on the gray scale image, which were spaced out evenly and tangentially. In a guideline (marked with a dotted white line), gray levels remapped along the line can be estimated as shown in

Figure 6(b). n edge detection is an inevitable mission for the estimation of the gap, which is defines by high image contrast pixels with black and white colors (Figure 4 (b)). The gray level (luminance) precipitously decreases in the intermediate area. Measurement points (dots in the red line) have a limitation to interpolate the points to pursue the rapid decrease. Two marked areas with a gray color (Figure 6(a)) indicate possible jumps of gray levels between nearest points, and therefore an appropriate interpolation is necessary.



(a)



(b)

Fig. 6. An example of the tangential section of the target crack to estimate the width of the crack.

4. Results

The proposed method was applied to the real environment data that collected by the specialized multi-copter [7]. After the crack detection (Figure 2; Detectors), the gauging of the width and length was done successfully. The evaluation was verified with the human expert data provided by Shin-Nippon Nondestructive Inspection Co., Ltd. The numerical analysis and visualization were derived from the programming code with MATLAB. Figure 7 and 8 showed the results.

According to the close distance between the setting position of proximity cameras and the concrete surface as shown in Figure 1, the original image was obtained as a 2D scenography image, and therefore the space correction as well as fish-eye correction was applied to convert the normal x-y axis coordinate image (equal length and width).

In this field experiment, ground truths (correct answer of the crack position and width) were described with the white chalk as shown in each panel of Figure 8.

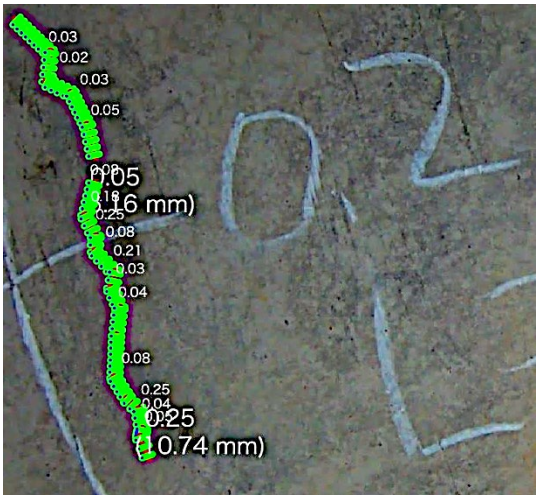
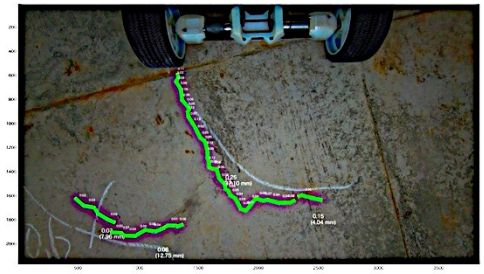


Fig. 7. A highlighted example of results by using the proposed width estimation method (The ground truth was 0.2mm and the estimation result was 0.25mm).

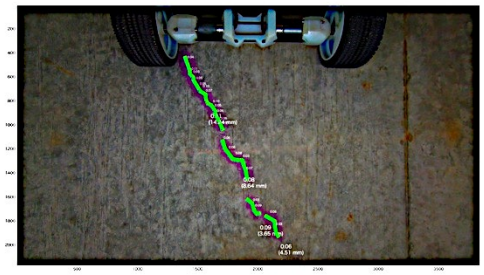
As shown in Figure 7, there is a difference between result of the proposed method and the white chalk marked by the human expert, in the sense of the connecting crack. Although lines are not connecting in the image obviously, the human expert tends to connect them if it seems to be a consistent line. Indeed, the tendency is beyond the image processing and requires a treatment of the semantic knowledge of humans. In further analyses, automated inspection systems will be developed including such a semantic knowledge-based scheme.

5. Conclusion

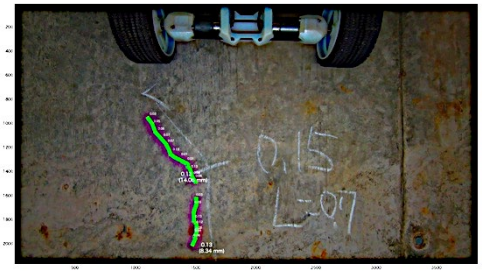
Our proposed method clearly demonstrated the length and width estimation of concrete cracks as the sub-pixel estimation to fit for the direction of extension of cracks even they were wandering. In further analyses, full automated concrete detection and estimation is expected [11], [12], [13], [14], [15], [16], [17], [18], [19], [20].



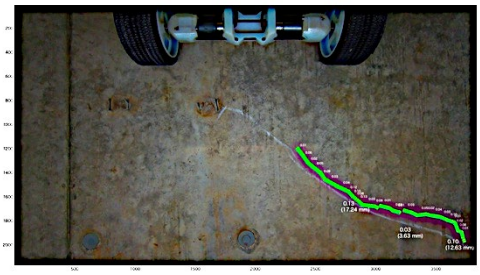
(a)



(b)



(c)

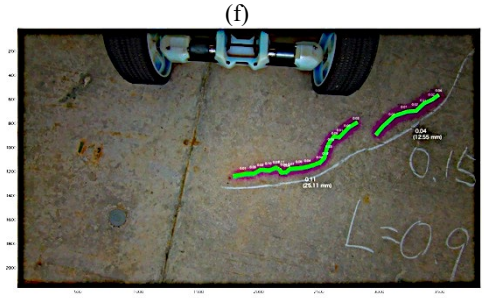


(d)

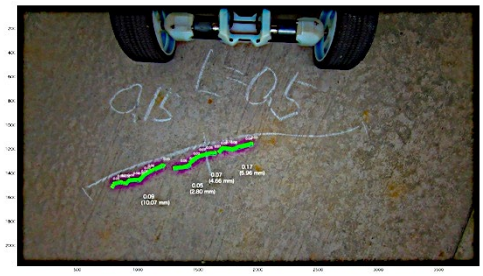
(e)

Fig. 7 Estimated widths and lengths of cracks superimposed on target images. The human measurement was described by chalk lines.

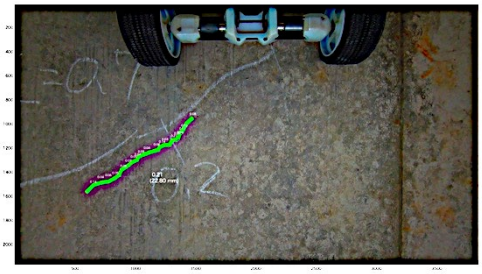
(f)



(g)



(h)



(i)

Fig. 8. Estimated widths and lengths of cracks superimposed on target images. The human measurement was described by chalk lines.

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