Automatic Crack Detection on Concrete Images Using Segmentation via Fuzzy C-means Clustering

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Abstract

Automatically detecting cracks in images of the concrete surfaces of bridge posts is an important safety task. Previous methods have only focused on very obvious crack images that were taken from very close to the surface. When photographing facilities with automated equipment such as drones, the camera is often more than one meter away from the surface in question. Thus, a precise method is required to detect cracks that are photographed at large distances from the surface. We propose a novel approach to detect 0.3 mm cracks in photographs taken at a distance of 1 m from the surface. The proposed method uses segmentation.. Filtering and morphological operations are applied to the image to make the cracks more distinguishable from the background. We separate crack candidates from the rest of the image using segmentation. Finally, we filter out noise and clutter using three masks. Experimental results demonstrate the effectiveness of the proposed method.

Keywords: crack, image processing, segmentation

1. Introduction

As natural disasters continue to occur frequently, interest in safety inspection of various facilities is increasing rapidly. Inspection is necessary to prevent the collapse of facilities. The inspection of facilities depends largely on visual evaluation; requiring an inspector to visit the facility directly and check for issues. Recently, people have begun inspecting facilities by examining photographs taken by aircraft such as drones in order to solve reduce costs. Because the inspector can control the aircraft from the ground to take outdoor photographs, and subsequently inspect them indoors, the costs associated with a direct inspection of the entire facility are mitigated.

When a drone is used to inspect a facility, it must approach the facility closely to examine small condition details. Because individual photographs do not capture a wide area of the facility, the inspector must capture many images with the drone to check the entire facility. Thus, hundreds or thousands of images must be carefully inspected, which is extremely time intensive.

Research is currently underway to reduce the cost and time required for inspection by automatically detecting cracks in images taken by drones and informing inspectors using computer vision technology. Because cracks have the characteristics of a line, detecting cracks using edge detection algorithms is very common.

Most edge detection methods are designed for images with highly visible concrete cracks, and it is necessary to find any cracks with a width of 0.3 mm or more, which is the standard measurement for safety inspection of various facilities.

We propose a new method to detect cracks with a width of 0.3 mm or more in images of concrete surfaces. There are many unnecessary elements in the images such as regularly occurring concrete dimples. These elements are called noise and require processing to be removed. Three types of noise removal methods are required to remove three different types of noise. They are used to remove extraneous features from the image for better detection of cracks on concrete surfaces [1]. The crack detection method for concrete surfaces using multiple noise reduction techniques is composed of three stages: segmentation, noise removal, and crack detection. First, we perform image segmentation using fuzzy c-means clustering [7]. Second, mask filtering of three sizes is applied to remove the three types of noise, leaving only the cracks. Experimental results demonstrate the effectiveness of the proposed method

2. Related Work

A crack detection method for photographs is a way of searching for cracks through preprocessing such as binarization or filtering of an RGB image of a concrete surface. Because noise is typically present in the captured image, filtering is used to leave only the cracked regions.

Yum et al. first converted color images into grayscale and then performed a global binarization by using a threshold value to show cracks as black and the background as white [2]. In order to remove noise after binarization, they first applied a median filter, and then removed residual noise by using a Gaussian filter. In the binarized image, non-cracked regions are removed using a region of interest (ROI) method. An image histogram of the cracks is then used to detect cracks in the horizontal and vertical axes.

Tung-Ching Su removed noise from images by applying a weighted median filter after converting color images taken by a digital camera into grayscale [3]. He then performed a morphology operation in six directions: of 0°, 30°, 60°, 90°, 120°, and 150°. He then combined the results of the six initial operations. Otsu's binarization is first performed to separate the background and the cracks, and again to set the crack detection criteria and divide the image into cracked and non-cracked sections [4].

Nishikawa et al. created an image filter to detect cracks using genetic programming. The filter was adjusted based on the resolution, average brightness, and standard deviation of the input image [5]. After removing noise by using an image filter, they found the end points and inflection points in the remaining cracks, then analyzed the distances and angles of the endpoint-endpoint and endpoint-inflection point relationships in different cracks to correctly connect the points.

Wenyu Zhang et al. determined image preprocessing and search areas by using average smoothing filtering and a black top-hat transformation on concrete images from tunnels [6]. They then separated the background and cracks by using a threshold and an opening operation from the morphology technique. After extracting images with crack characteristics and learning using an Extreme Learning Machine (ELM) approach, noise is removed from the image and only the cracks remain.

3. Crack Detection with Segmentation and Multiple Noise Reduction

The structure of the automatic crack detection scheme is outlined in Figure 1. In the first step, Image Segmentation is applied to the concrete image. Next, only the images containing cracks are extracted from the segmentation results. In the second step, we remove noise from the previously extracted crack images using a multiple noise reduction method. In the final step, the final result in obtained through an AND operation between the segmentation results containing cracks and the results of multiple noise reduction.

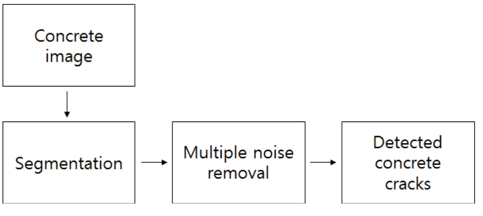

Figure 1. Concrete crack detection scheme.

3.1 Segmentation

This step consists of leaving only image clusters containing cracks by applying image segmentation using fuzzy c-means clustering on the image. Fuzzy c-means clustering is a clustering method using fuzzy sets based on the probability of a point belonging to each cluster and its distance from the cluster.

We have set the fuzziness exponent to 2 and the number of clusters to 3. Figure 2 shows segmentation results based on the number of clusters. As C increases, noise is reduced, but cracks are lost. Because the primary goal is to find the cracks rather reduce the noise, we set the number of clusters to 3.

Because the user does not need to intervene during the segmentation process other than choosing the number of clusters and the fuzzy parameter, and because fuzzy c-means clustering is less influenced by the initial data, segmentation using fuzzy c-means clustering is a good choice for an automatic crack detection method.

After applying the segmentation, we select only the clusters that contain cracks from the results. The selection is based on the average brightness of the pixels belonging to cluster. This is because concrete cracks are darker than the background. We then choose the clusters with the lowest average brightness level. The ratio of the selected clustered pixels over all captured pixels is 20% or less.

Figure 3 displays the results of segmentation. Clusters (b) and (c) are the background. Image (a) contains crack elements. Cluster (d) is the selected cluster where the average brightness of the pixels is the lowest.

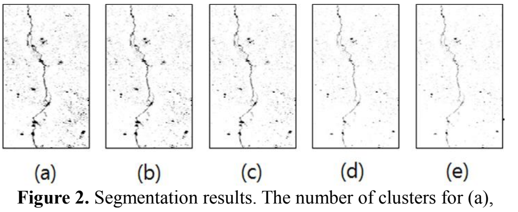

Figure 2. Segmentation results. The number of clusters for (a), (b), (c), (d) and (e) is 2, 3, 4, 5, and 6, respectively.

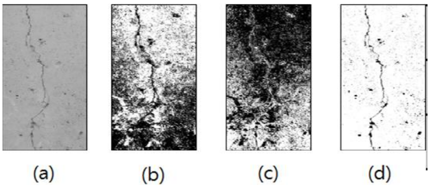

Figure 3. (a) is a concrete image; (b), (c), and (d) are clusters.

3.2 Multiple noise reduction

This process removes noise from the clusters containing the cracks. Prior to performing noise removal, we applied a morphology dilation operation to reveal the characteristics of the cracks and prevent them from being removed during the noise removal process. The dilation operation consists of repeatedly extending the area of a specific object in the image. In this work, an ellipse shaped dilation operation is used.. The expanded portions of the crack remain in the subsequent process.

After expanding the cracks using the morphology technique, we remove the noise that appears around the cracks. Because cracks have the characteristics of lines, we create a 3x7 mask to find vertical components and a 7x3 mask to find horizontal components. We then filter the images using both masks .

We find pixels with a mask-like shape and leave them black while erasing pixels that do not have a shape similar to the masks. This mask is a nonlinear filter that removes pixels in the middle if the number of pixels in the mask is less than a certain fraction of the total mask. The rate depends on whether the primary goal is to find the crack or to reduce noise. In this experiment, we set the ratio to 100%.

Figure 4 displays the extraction of the horizontal and the vertical crack components. The irregular portion that does not have a line shape decreases in intensity. We then combine the two components and leave only the overlapping parts, further decrease the intensity.

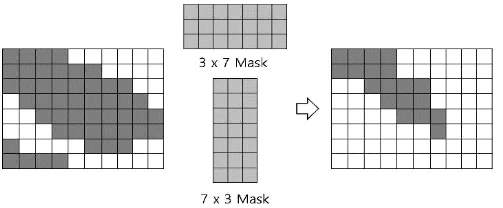

Figure 4. Noise removal method using horizontal and vertical component masks.

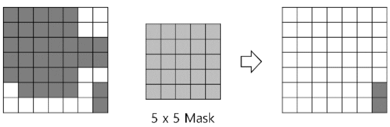

Figure 5. Example of filtering with 5 x 5 mask and grassfire search algorithm.

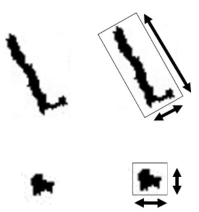

Figure 6. The top image is a crack and the bottom image is noise.

Some noise has been removed by the previous procedure, but additional noise still remains. In order to remove it, a large chunk of the image is reduced leaving only a small chunk, and then small chunks are subtracted from the image. we create a 5x5 mask and place it on the image as a Grassfire search to find and delete connected noise areas, meaning pixels whose masks are filled with black. The Grassfire search is a method of labeling neighboring pixels in the order of right, bottom, left, and top for an arbitrary pixel. After the Grassfire search, we delete the groups containing the labelled pixels. Finally, the remaining pixels from the image are removed. Figure 5 displays noise removal using the 5x5 mask.

However, more noise still remains. In order to remove it, we perform connected-component labeling. First, we obtain a rectangle bounding all pixels belonging to a given label using the rotating calipers algorithm. We then find the ratio of the long and short sides of the rectangle. If the ratio is greater than 2, the region is regarded as a crack. Otherwise, it is regarded as noise, because cracks have the characteristics of lines.

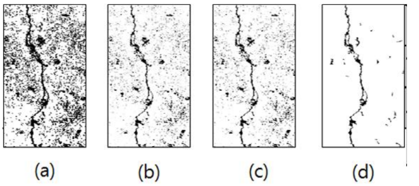

Figure 7. Procedure for noise removal. (a) is the result of the dilation operation, (b) is obtained via horizontal and vertical component masks, (c) is the image after 5 x 5 mask filtering with the grassfire algorithm, and (d) is the result of noise removal via comparison of long axis and short axis.

Because we performed a dilation operation during the multiple noise reduction process, the noise removal results are slightly wider than the actual cracks, and the remaining noise also appears larger. In order to obtain a similar result to the actual crack, the result is compared with the segmentation results described in section 3.1, leaving only the that overlap each other and remove all other pixels. Figure 8 displays the resulting overlapped areas left by the AND operation. and the final results of the crack detection process.

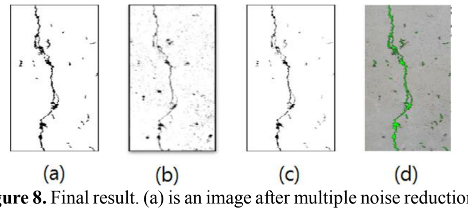

Figure 8. Final result. (a) is an image after multiple noise reduction, (b) shows the clusters containing cracks (c) is the result of the AND operation performed on (a) and (b), and (d) shows the overlapping region.

4. Experimental Result

Figures 9 and 10 present a comparison of the proposed method with Sobel detector segmentation [8]**.** The resulting images after using the Sobel detection algorithm contain more noise than the clustering results of segmentation using fuzzy c-means clustering. If the threshold is set too high after Sobel detection is applied, many cracks are removed from the concrete images.

In order to obtain result images with more cracks and less noise using a Sobel detector with a threshold, the threshold value should be adjusted based on the surface conditions in the concrete crack image, or based on image brightness. However, when using segmentation via fuzzy c-means clustering, the results of segmentation are better than the results of the sobel detector, even when the number of clusters is fixed.

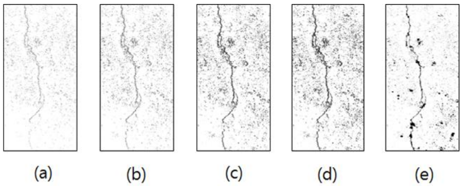

Figure 9. Examples of Sobel detection and fuzzy-c means clustering. (a), (b), (c), and (d) are the results of Sobel edge detection with a threshold. The thresholds for (a), (b), (c), and (d) are 150, 130, 90, and 50, respectively. (e) is the clustering result for fuzzy c-means clustering.

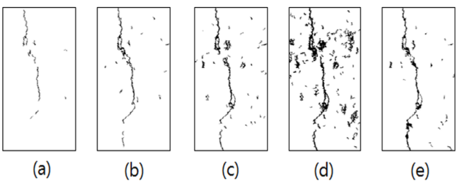

Figure 10. Results of noise removal process shown in Figure 8. (a), (b), (c), (d), and (e) are the results of the multiple noise reduction steps in Figure 8.

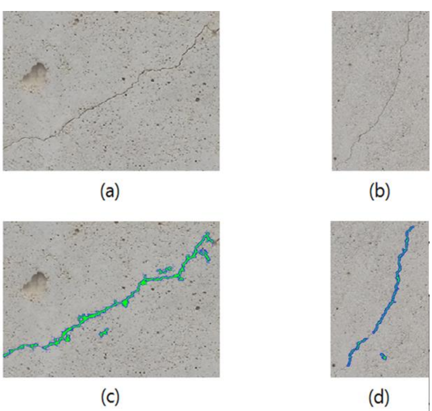

Figure 11. Results of the proposed method.

5. Discussion and Conclusion

We proposed a method to automatically detect cracks in images of concrete through segmentation using fuzzy c-means clustering and multiple noise reduction. The newly proposed method achieves better performance than the method in our previous study. Tables 1 and 2 display the experimental results for 50 real concrete photographs taken from 1 m away with a 4K resolution camera. The experimental results for cracked concrete images in Table 3 indicate that the proposed method is effective for crack detection. The newly proposed method achieves higher recall and precision than our previous work. However, if the clusters containing the cracks also contain lots of noise, crack detection is much less successful.

TABLE 1.
CONFUSION MATRIX FOR OUR PREVIOUS METHOD

		Detection	
		True	False
Actual	True	17	8
	False	6	19

TABLE 2.
CONFUSION MATRIX FOR PROPOSED METHOD

		Detection	
		True	False
Actual	True	20	5
	False	2	23

TABLE 3.
RECALL AND PRECISION COMPARISON

Method	Recall	Precision
Previous method	0.68	0.73
Proposed method	0.8	0.9

Knowledgements

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