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스케일링을 이용한 다중 스케일 균열 검출

(Multi-scale Crack Detection Using Scaling)

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요 약

본 논문에서는 스케일링을 이용한 다중 스케일 균열 검출 방법을 제안한다. 제안하는 방법은 형태학 알고리즘, 균열 특징, 스케일링을 기반으로 한다. 사용하는 형태학 연산자는 균열의 패턴을 추출한다. 열림과 닫힘의 연산을 이용하여 균열과 배경을 구분한다. 형태학을 기반으로 하는 분할은 작은 간격의 균열을 검출하는 기존의 차분 이용 통합 방법 보다 좋은 성능을 보인다. 그러나, 형태학 방법들은 오직 하나의 구조 연산자를 사용하면 고정된 크기의 균열만을 검출할 수 있다. 따라서 스케일링 방법을 사용한다. 스케일링에 이중선형 보간법을 사용한다. 제안하는 방법은 분할된 영역의 화소 수와 최대 길이와 같은 특징들의 값들을 계산한다. 구분된 영역이 균열에 해당하는 지를 계산한 특징들의 값들에 의하여 결정한다. 실험 결과에서 제안한 다중 스케일 균열 검출 방법이 기존의 검출 방법들보다 향상된 결과를 보인다.

Abstract

In this paper, we propose a multi-scale crack detection method using scaling. It is based on morphology algorithm, crack features, and scaling. We use a morphology operator which extracts patterns of crack. It segments cracks and background using opening and closing operations. Morphology based segmentation is better than existing integration methods using subtraction in detecting a crack it has small width. However, morphology methods using only one structure element could detect only fixed width crack. Thus, we use a scaling method. We use bilinear interpolation for scaling. Our method calculates values of properties such as the number of pixels and the maximum length of the segmented region. We decide whether the segmented region belongs to cracks according to those data. Experimental results show that our proposed multi-scale crack detection method has better results than those of existing detection methods.

Keywords : Multi-scale, crack detection, morphology, shape properties.

Ⅰ. Introduction

Image processing for inspection is increasing in various field. Cracks are important clues to indicate significant structure damages. Cracks on concrete surfaces are one of the earliest indications of degradation. The popular methods for crack detection are to manually measure the condition of the concrete. However, the manual methods depend on the specialist's knowledge and experience and lack objectivity. Thus, we focus on image-based crack detection using scaling and shape properties.

There is a need to detect cracks reliably. However, images are contaminated by noises such as blemishes, divots, and shading. Thus, in spite of the noises, reliable extraction of crack patterns is important for crack detection.

For many years, various crack detection methods are proposed. Integrated algorithms which are composed of two steps are proposed[1~4]. In the first

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step, the pre-processing is used to reduce noise and get the subtraction image. In the second step, thresholding is used to separate crack regions from the background.

Morphology methods are proposed to segment regions cracks from background[5~8]. They are based on opening and closing operations. These methods extract useful information and segment cracks and background in images. However, if these methods use big structure element, small crack patterns with thin width are removed as noise. Thus, user should control the size of the structure element.

Percolation methods are proposed to detect cracks [9~10]. The shape information of crack is used to detect. However, these methods are only based on the brightness values, they have problems to get crack properties in noisy images.

In this paper, we propose a multi-crack detection method using scaling. We use bilinear interpolation for scaling. Our proposed algorithm is based on morphology algorithm, crack features, and scaling. We assume that an input image is contaminated by various noises[11~13]. In our proposed algorithm, a method using morphology operator extracts patterns of crack. Morphology based segmentation is better than existing integration methods using subtraction in detecting a crack. Also, it is robust to noisy environment. However, morphology methods using only one structure element could detect only fixed width crack. Thus, we use a scaling method. We use bilinear interpolation instead using structure elements with various size which cause heavy load of operations. Also, shape properties of cracks are considered to detect cracks in our proposed methods.

Ⅱ. Existing crack detection methods

In existing crack detection methods, they proposed crack detection methods which are generally consist of two stages. In the first stage, pre-processing which reduces noise and gets subtraction image is performed. To reduce noise, smoothing filter such as median or gaussian filter is used. Also, subtraction

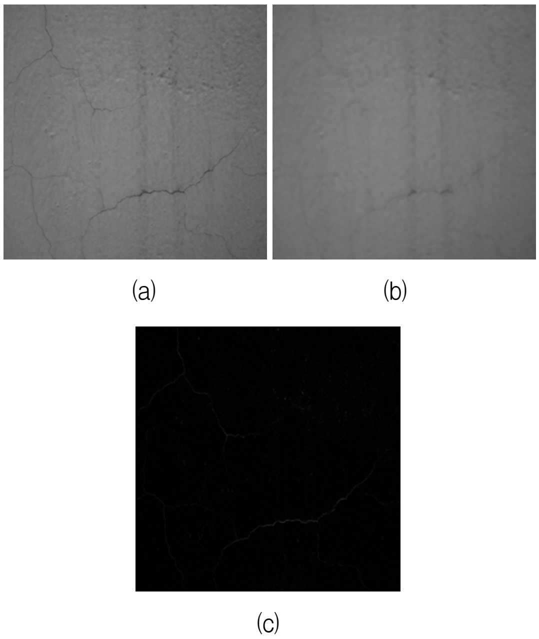


그림 1. (a) 가는 균열을 가진 테스트 원 영상, (b) 필터링 후 영상, (c) 차 영상
Fig. 1. (a) Test original image with thin width crack, (b) Filtered image, (c) Subtracted image.

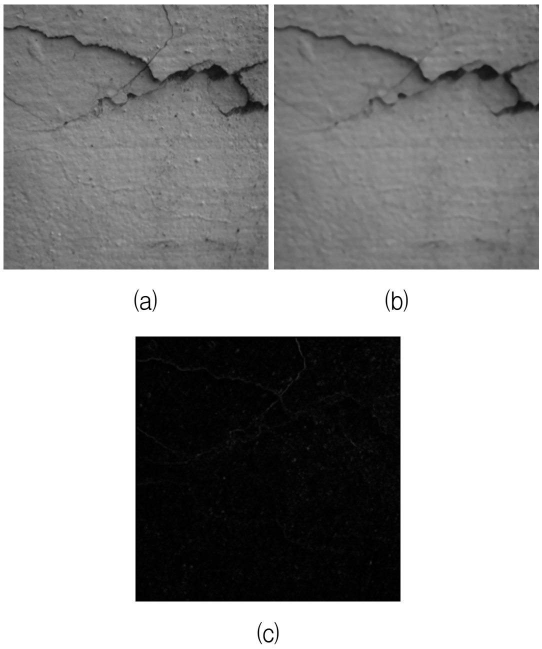


그림 2. (a) 굵은 균열을 가진 테스트 원 영상, (b) 필터링 후 영상, (c) 차 영상
Fig. 2. (a) Test original image with thick width crack, (b) Filtered image, (c) Subtracted image

image is obtained by subtracting the original image from the smoothed image which is filtered. Fig. 1. and Fig. 2 show those images.

In the second stage, segmentation by thresholding is operated. The thresholding operation is performed

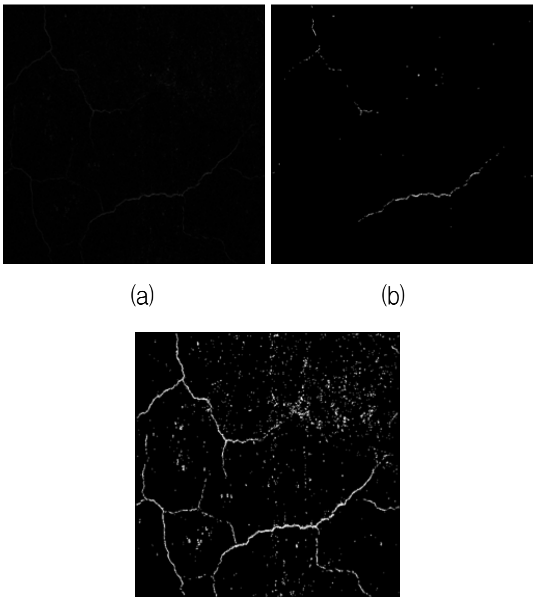


그림 3. (a) 가는 균열 환경에서 7x7 미디언 필터링 된 영상과 원 영상과의 차 영상, (b) 최대 엔트로피 방법의 임계치 영상, (c) Otsu 방법의 임계치 영상

Fig. 3. (a) Subtracted image between 7x7 median filtering and original images with thin width crack, (b) Thresholding image using maximum entropy method, (c) Thresholding image using Otsu's method.

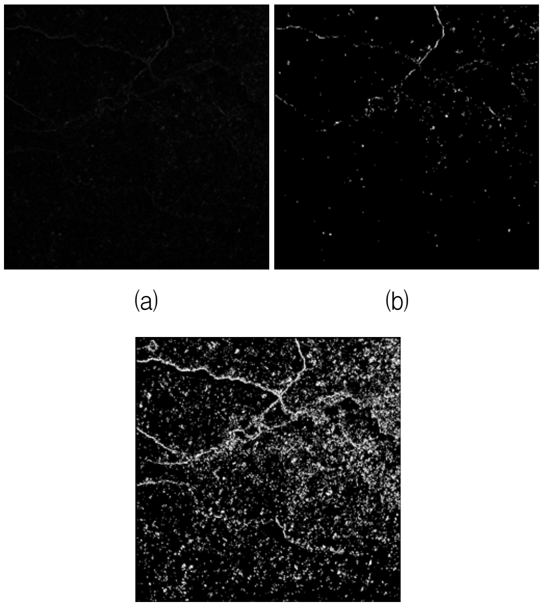


Fig. 4. (a) 굵은 균열 환경에서 7x7 미디언 필터링 된 영상과 원 영상과의 차 영상, (b) 최대 엔트로피 방법의 임계치 영상, (c) Otsu 방법의 임계치 영상

Fig. 4. (a) Subtracted image between 7x7 median filtering and original images with thick width crack, (b) Thresholding image using maximum entropy method, (c) Thresholding image using Otsu's method.

on the subtracted images. There are several methods such as Otsu[3] and maximum entropy[4]. Otsu's thresholding method segments dark regions such as cracks from the background image. Maximum entropy method maximizes inter-class entropy instead of maximizing inter-class variance like Otsu's method. As shown in Fig. 3 and Fig 4, these methods have problems in detecting thick-width cracks. Furthermore, thresholding method using Otsu's algorithm has better performance than those of maximum entropy method.

Ⅲ. Proposed crack detection

The proposed multi-crack detection algorithm is based on morphology, shape properties, and scaling. It has four stages. Fig. 5 shows the flowchart of the proposed crack detection method.

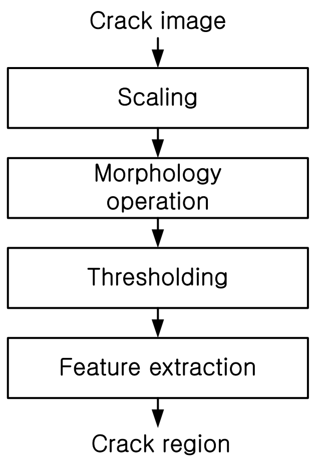


그림 5. 제안하는 균열 검출 알고리즘의 블록도

Fig. 5. Block diagram of the proposed crack detection algorithm.

First, scaling using bilinear interpolation is performed. According to the size of the crack width, we scale down an input image. In our proposed algorithm, downscalings as 1, 1/2, 1/4, 1/8 times

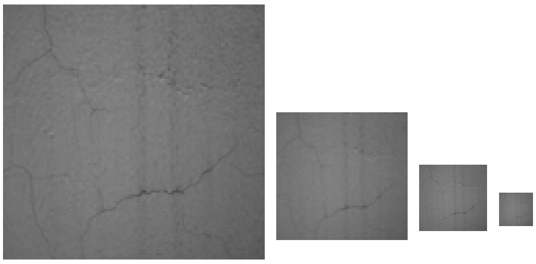


그림 6. 축소된 영상들
Fig. 6. Down-scaled images.

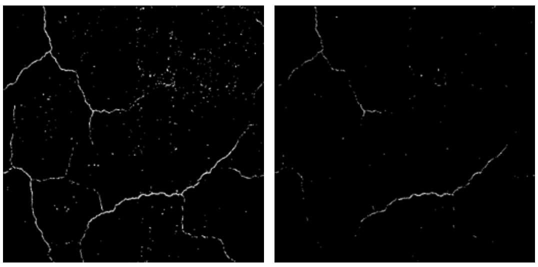
using bilinear transform are performed. Fig. 6 shows an input image and the down-scaled images.

Second, the proposed algorithm segments crack regions from the background image. The proposed segmentation uses opening and closing operations of morphology[5] given by

$$Y = \max[(X \bigcirc S_{0°,45°,90°,135°}) \bullet S_{0°,45°,90°,135°}, X] - X, \quad (1)$$

where, $\bigcirc$ and $\bullet$ are opening and closing operations, respectively. We use structure elements according to four directions. Fig. 7 shows the segmentation image using the morphology operation.

그림 7. 형태학 연산을 이용한 영역 분할 영상
Fig. 7. Segmentation image using the morphology operation.



(a) (b)

그림 8. 임계치 영상 (a) Otsu, (b) 최대 엔트로피
Fig. 8. Thresholded images using (a) Otsu, (b) Maximum entropy.

Third, in proposed algorithm, image obtained from morphological operations is thresholded by Otsu's thresholding method[3]. In Fig. 8, we show that Otsu's method is better than maximum entropy method in image using morphological operations.

Finally, we extract features using crack properties and remove regions of noise from segmented cracks regions. Fig. 9 shows the extracted crack regions from the background image without noisy clustering regions. Our feature extraction and removing noisy cluster regions are performed as follows

$$\begin{aligned} &F = 1, \text{ if } C_n > T_n \text{ and } C_f > T_f \\ &F = 0, \textit{otherwise}, \end{aligned} \quad (2)$$

where F is final crack decision, C_n, T_n, C_f, T_f are cluster number, threshold cluster number, feature value, threshold feature value, respectively. C_f could be circularity feature, eccentricity, aspect ration, etc. We choose the circularity feature which is given by $\frac{4C_n}{\pi L_{\max}^2}$. $L_{\max}$ means the maximum length of the cluster region. After iteratively operations according to scaling down size 1, 1/2, 1/4, 1/8 times, the results are combined to the final crack detection image. Fig. 10 shows the detected final crack image.

그림 9. 추출된 균열 영상
Fig. 9. Extracted crack image.

그림 10. 스케일링을 이용한 검출된 최종 균열
Fig. 10. Detected final crack image using scaling.

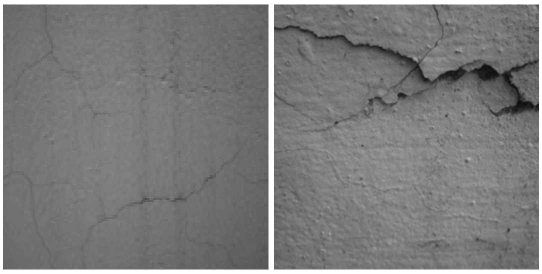
Ⅳ. Experimental results

In this section, the proposed algorithm and existing detection algorithm[4] are simulated on several crack images, and the results are compared. Fig. 11 shows test images; "Crack1", "Crack2", "Crack3", "Crack4", and "Crack5". Fig. 12 shows synthetic crack images which are manually sketched for simulations.

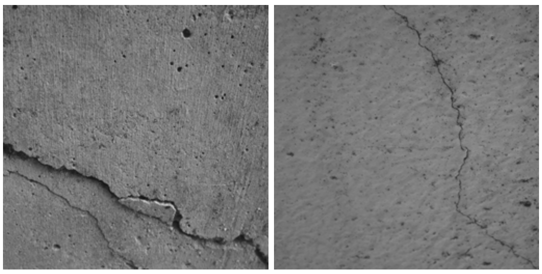
Fig. 13~Fig. 17 show extracted crack images using existing and our proposed method.

For comparison, we perform a sensitivity and precision analysis[9] given by

$$Sensitivity = \frac{C_t \cap C_d}{C_t} \tag{3}$$



(a) (b)



(c) (d)

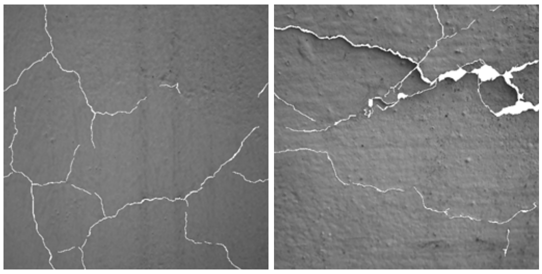
(e)

그림 11. 테스트 균열 영상들. (a) Crack1, (b) Crack2, (c) Crack3, (d) Crack4, (e) Crack5

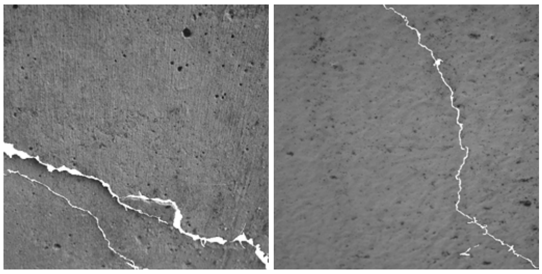
Fig. 11. Test crack images. (a) Crack1, (b) Crack2, (c) Crack3, (d) Crack4, (e) Crack5

$$Precision = \frac{C_t \cap C_d}{C_d} \tag{4}$$

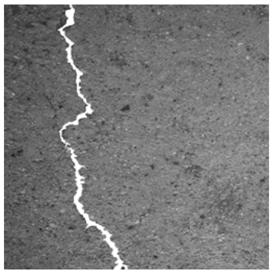
where C_t, C_d are real crack pixels and detected



(a) (b)



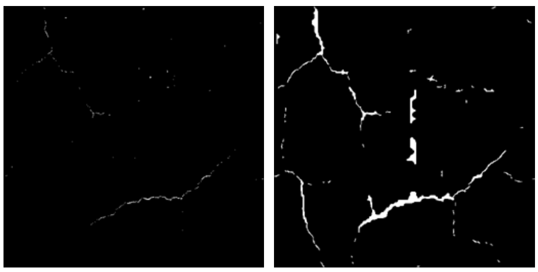
(c) (d)



(e)

그림 12. 합성한 균열 영상들. (a) Crack1, (b) Crack2, (c) Crack3, (d) Crack4, (e) Crack5

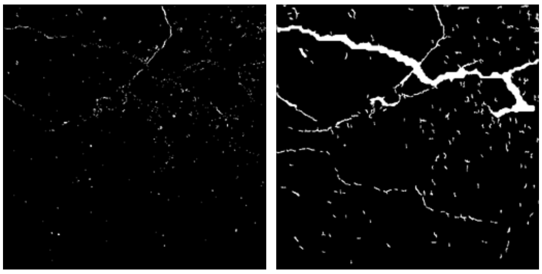
Fig. 12. Synthetic crack images for (a) Crack1, (b) Crack2, (c) Crack3, (d) Crack4, (e) Crack5



(a) (b)

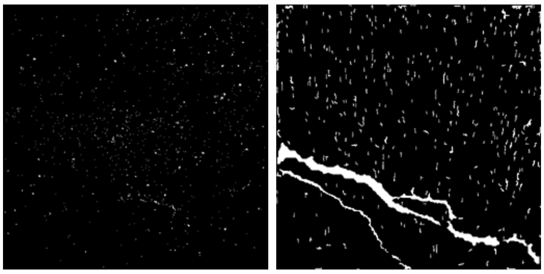
그림 13. Crack1에서 추출된 균열 영상들. (a) 기존 방법 [4], (b) 제안하는 방법

Fig. 13. Extracted crack images from Crack1. (a) Existing method [4], (b) Proposed method



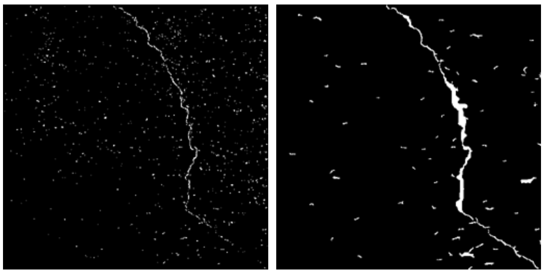
(a) (b)

그림 14. Crack2에서 추출된 균열 영상들. (a) 기존 방법 [4], (b) 제안하는 방법
Fig. 14. Extracted crack images from Crack2. (a) Existing method [4], (b) Proposed method



(a) (b)

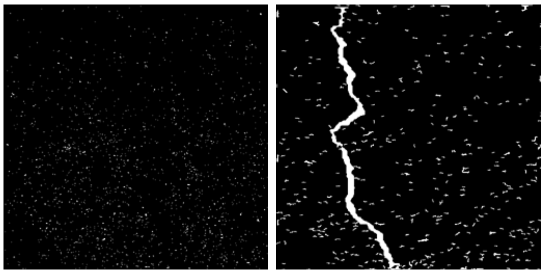
그림 15. Crack3에서 추출된 균열 영상들. (a) 기존 방법 [4], (b) 제안하는 방법
Fig. 15. Extracted crack images from Crack3. (a) Existing method [4], (b) Proposed method.



(a) (b)

그림 16. Crack4에서 추출된 균열 영상들. (a) 기존 방법 [4], (b) 제안하는 방법
Fig. 16. Extracted crack images from Crack4. (a) Existing method [4], (b) Proposed method

crack pixels, respectively. C_t is given as shown in Fig. 12. C_d is given as shown in Fig. 13~Fig. 17. Experimentally, we set T_n, T_f values as 7 and 0.5. If we choose bigger T_n, more small dots of noise can be removed. Also, if we choose smaller T_f, more thinner lines can be selected as cracks. As shown in Table 1 and Table 2, our proposed method detects crack pixels more correctly than existing method[4].



(a) (b)

그림 17. Crack5에서 추출된 균열 영상들. (a) 기존 방법 [4], (b) 제안하는 방법
Fig. 17. Extracted crack images from Crack5. (a) Existing method [4], (b) Proposed method

표 1. 감응도 결과
Table 1. Sensitivity results.

	Existing method [4]	Proposed method
Crack1	0.12	0.58
Crack2	0.08	0.70
Crack3	0.01	0.81
Crack4	0.42	0.83
Crack5	0.02	0.85
Average	0.13	0.75

표 2. 정밀도 결과
Table 2. Precision results.

	Existing method [4]	Proposed method
Crack1	0.88	0.30
Crack2	0.38	0.42
Crack3	0.02	0.31
Crack4	0.26	0.33
Crack5	0.03	0.38
Average	0.31	0.35

V. Conclusions

We proposed an efficient multi-crack detection method based on scaling, morphology, and extraction using shape properties. In our proposed method, bilinear interpolation is used to scale image. Proposed algorithm segments crack regions from the background image and thresholds using Otsu method. For detect crack regions correctly, our proposed algorithm removes the noisy clusters using extracted features.

Experimental results show the proposed method has better performance of multi-scale crack detection than those of the conventional methods.

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