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Phân tích vết nứt từ hình ảnh bề mặt kết cấu với công cụ Surface Crack Analysis

Image processing based building crack detection using Surface Crack Analysis program

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Tóm tắt

Phát hiện và phân tích vết nứt là một nhiệm vụ quan trọng trong giai đoạn khảo sát công trình xây dựng. Quy trình thủ công thông thường được sử dụng để phát hiện vết nứt rất tốn thời gian và dễ bị tác động bởi đánh giá chủ quan của con người. Nghiên cứu này thiết lập một chương trình, được đặt tên là Surface Crack Analysis, dựa trên các kỹ thuật xử lý hình ảnh để nhận dạng và phân tích vết nứt tự động. Surface Crack Analysis đã được phát triển trong môi trường Visual C# .NET để dễ dàng ứng dụng trong thực tế. Chương trình này sử dụng một phương pháp điều chỉnh cường độ xám, được gọi là phân biệt cấp độ xám tối thiểu (M2GLD), để cải thiện hình ảnh và phương pháp Otsu để phân ngưỡng hình ảnh. Kết quả thử nghiệm cho thấy, chương trình có thể phát hiện thành công các vết nứt trên hình ảnh kỹ thuật số. Do đó, chương trình mới được xây dựng có thể là một sự thay thế cho các cơ quan quản lý công trình trong nhiệm vụ khảo sát xây dựng.

Từ khóa: Phát hiện vết nứt; Phân ngưỡng hình ảnh; Khảo sát công trình; Phân tích vết nứt.

Abstract

Detecting and analyzing cracks is an important task during the phase of building condition survey. The conventional manual process of crack detection is very time-consuming and susceptible to subjective judgments of inspectors. This study establishes a program, named as Surface Crack Analysis, based on image processing techniques for automatic crack recognition and analyses. The Surface Crack Analysis has been developed in Visual C# .NET to ease its implementation. The program employs a gray intensity adjustment method, called Min-Max Gray Level Discrimination (M2GLD), for image enhancement and Otsu method for image binarization. Experimental results show that the program can successfully detect cracks in digital images. Hence, the newly constructed program can be an alternative for building management agencies in the task of building condition survey.

Key words: Crack Detection; Image Binarization; Building Survey; Crack Analysis.

1. Introduction

Cracks on surface of structure have always been a major concern of building owners as well as structural engineers. It is because cracks may strongly affect the safety, durability, and serviceability of structures [1, 2]. Cracks bring about the reduction in the effective loading area which leads to the increase of stress and

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subsequently failure of the concrete or other structures [3]. Especially for concrete elements, cracks create access to harmful and corrosive chemicals to penetrate into building structures, which consequently deteriorate their integrity as well as aesthetics [4, 5].

As pointed out by previous studies, surface cracks are critical indicators of structural damage and durability of all types of structure. Thatoi et al. [6] and Koch et al. [7] stated that it is crucial to visually inspect the building elements to recognize cracks and assess the physical and functional condition. Nevertheless, the task of crack detection in building in developing countries like Vietnam is often performed manually. Thus, to obtain the measurements of cracks and to compile or process relevant data requires a significant amount of labor time and cost [8]. Moreover, inspection by means of human vision is inefficient in terms of both cost and accuracy because it involves the subjective judgments and experience of the building inspectors.

Therefore, a fast and reliable surface crack detection and analysis by means of image processing techniques is highly helpful to boost the productivity of the traditional way of building inspection [9]. Recent review works performed by [7], [10], [9], and [11] pointed out an increasing trend of applying image processing techniques for detecting crack in structures. These review works point out that evaluating the visual condition of vertical and horizontal structural elements become a vital part of civil engineering. The information of cracks can be employed for deeper diagnosis and to aid the decision making process regarding rehabilitation method selection to fix the damaged structures [12].

Among image processing techniques, image binarization [13, 14] is very suitable to be used for crack detection because cracks have distinguishable lines and curves [5, 15, 16]. The widely employed method of image binarization is the Otsu algorithm [17]. Although this algorithm has solid mathematical background and acceptable performance in many cases, applying the standard Otsu binarization method on real-world images of structures often cannot yield satisfactory outcomes. It is because image binarization depends on the image quality, characteristics of the background surface as well as associated parameters [9]. Real-world images also suffer from difficulties including low contrast, uneven illumination, noise pollution, existence of shading, blemishes, or concrete spall in images [11]. Hence, improvement or modification to the standard Otsu method for image binarizing is necessary.

In this study, an image processing program that automatically detects and analyses cracks in the digital image of surfaces of building elements is developed in Visual C# .NET Framework. The proposed program automatically recognize crack pixels out of image background but also perform various measurements of crack characteristics including the area, width, and orientation. An image enhancement algorithm called Min-Max Gray Level Discrimination (M2GLD) is employed to preprocess the images so that it is able to obtain more accurate crack detection outcomes.

2. Research methodology

2.1. Otsu method for image binarization

The Otsu's approach [17] is a widely employed for image thresholding. The fundamental idea of the Otsu's approach is to categorize the pixels of a digital image into two groups: the object of interest and the background. The separated object is featured by ω_0 and μ_0 which are the ratio of the number of pixels and the average gray level [16]. Similarly, the background of the image also has the two parameters of ω_1 and μ_1. Thus, the total mean of gray level of the image is defined as follows [17]:

$$\mu = \omega_0(t)\mu_0(t) + \omega_1(t)\mu_1(t), \quad (1)$$

where t denotes a gray level of the image.

The image is optimally binarized if the following optimization function $f_s(t)$ is maximized [16]:

$$Arg\ \underset{t}{Max}\ f_s(t) = \omega_0(t)(\mu_0(t)-\mu)^2 + \omega_1(t)(\mu_1(t)-\mu)^2. \quad (2)$$

The value of the gray level t_{op} corresponding to the maximal value of f_s is chosen as the thresholding value for image binarization [17]. In fact, if the histogram of the gray level of the image has two separable peaks, the Otsu method is capable of locating an optimum value of t_{op} locating between such two peaks corrrectly. Nevertheless, in the cases of unimodal and close-to unimodal histograms of images, this method may encounter difficulties in identifying a satisfying value of t_{op} [5].

2.2. Min-Max gray level discrimination for image enhancement

Because of the specific characteristic of cracks that consist of distinguishable lines and curves, the gray-scale value of the crack is often a local minimum within an image [5]. In order to separate the pixels of the image into crack and non-crack groups, a simple technique called Min-Max Gray Level Discrimination (M2GLD) [5] is employed as an image preprocessing step before the Otsu method is used for image binarization.

Let $I_o(m,n)$ be the gray intensity of pixel at the coordination (m, n) within an image, this gray intensity of the image is transformed using the following rules [5]:

$I_A(m,n) = \min(I_{o\_max}, I_o(m,n).R_A)$ if $I_o(m,n) > I_{o\_min} + \tau.(I_{o\_max} - I_{o\_min})$ (3)

$I_A(m,n) = \max(I_{o\_min}, I_o(m,n).R_A^{-1})$ if $I_o(m,n) \leq I_{o\_min} + \tau.(I_{o\_max} - I_{o\_min})$ (4)

where $I_A(m,n)$ is the adjusted gray intensity of the pixel at position (m,n). R_A denotes the adjusting ratio. I_{o_max} and I_{o_min} represent the maximum and minimum values of the gray intensity of the original image. τ denotes a margin parameter.

3. The Surface Crack Analysis program

This section of the article describes the basic structure of the proposed image processing system designed for detecting surface crack in building structure. The model has been developed in Visual C# .NET framework and can be used with ease to recognize and analyze cracks on surface of various elements in building, e.g. concrete beam, slab, floor, and wall. The model architecture is shown in Fig. 1. The interface of the program is illustrated in Fig. 2. The original image acquired from digital camera is input of the program. The original image is then denoised using median filter with a window size of 3x3 pixels. Median filter can significantly help to smooth the image to cast out unwanted dot noise. The image is subsequently preprocessed by the M2GLD algorithm and then binarized by the Otsu method.

Based on the binarized image, the properties of cracks are analyzed. First, the area of a crack object is simply computed as the total number of pixels located within the object boundary. Second, the crack orientation calculation can be boiled down to a simple linear regression problem within which the independent variable is the pixel position along X axis and the dependent variable is the pixel position along Y axis. The orientation of the crack is estimated via the slope of the regression line [5].

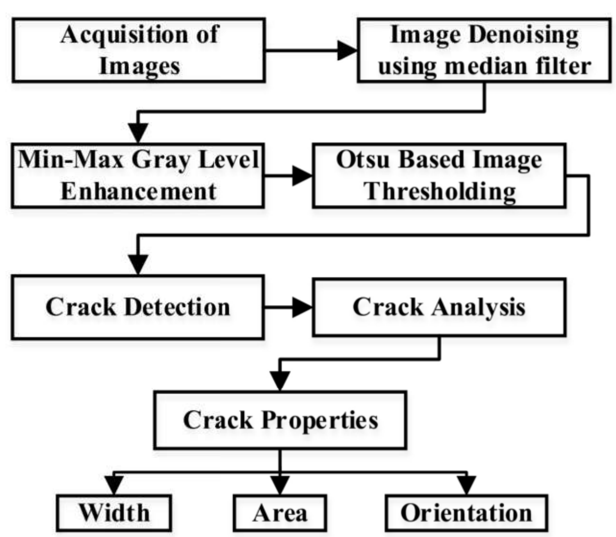

Fig. 1. Model Structure

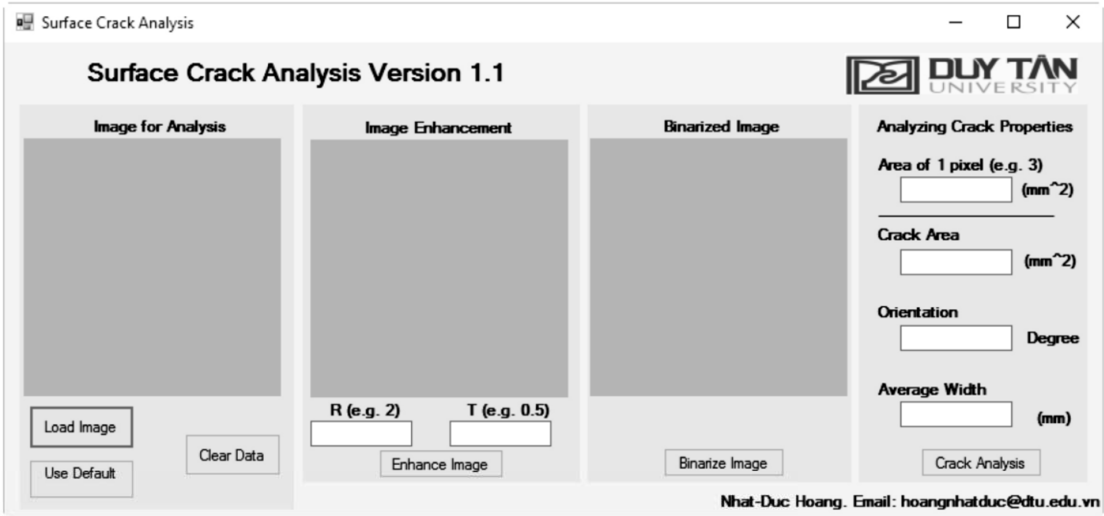

Fig. 2. Program interface

Third, the calculation of the crack width is separated into two cases: Case 1 is crack orientation ≤ 45° and Case 2 is crack orientation > 45°. Case 1 is for a crack object that resembles a horizontal crack and Case 2 is for a crack object that tends towards a vertical crack. The equation for estimating the crack width at a section *s* of the crack object (denoted as *W*(*s*)) in two cases are provided as follows [5]:

Case 1: $W(s) = L_v(s).\sin(90-\alpha)$ (5)

Case 2: $W(s) = L_h(s).\sin(\alpha)$ (6)

where $L_v(s)$ and $L_h(s)$ denote the number of crack pixels measured in vertical and horizontal directions at the section *s*. α represents the orientation of the crack object.

4. Applications

The proposed program for crack detection and analysis is verified with a set of testing images. The parameters of the program are empirically set as follows: The adjusting ratio: $R_A = 2$. The margin parameter: $\tau = 0.5$. The crack detection results are reported from Fig. 3 to Fig. 5. In all testing images, the crack pixels revealed by the proposed method are apparently clear and well separated from the surface structure. In addition, the cracks found by the proposed program clearly resemble the actual crack objects in the digital images. Thus, it is able to conclude that the newly constructed program can be a useful tool for practical application of crack detection in building structure.

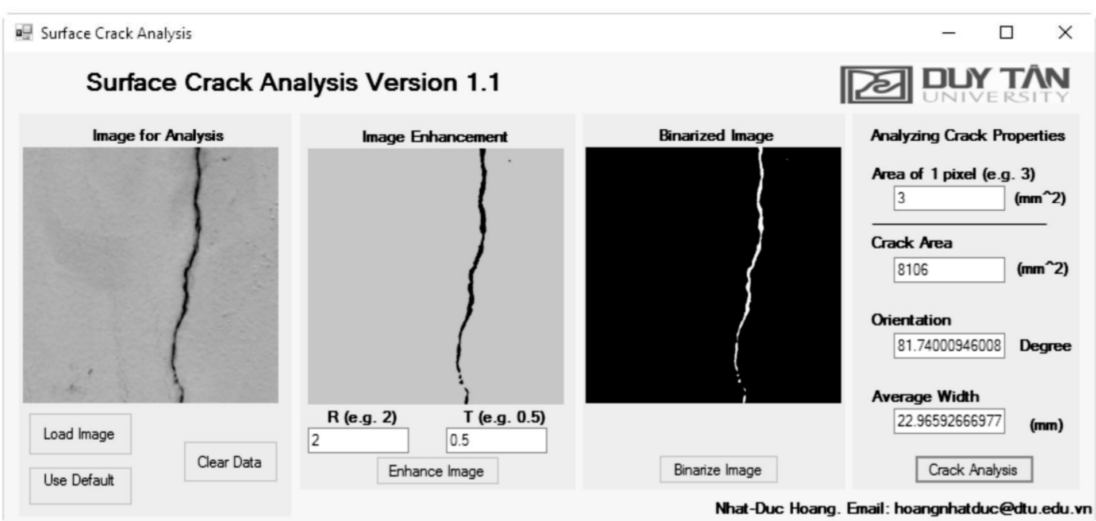

Fig. 3. Analysis result of the testing image number 1

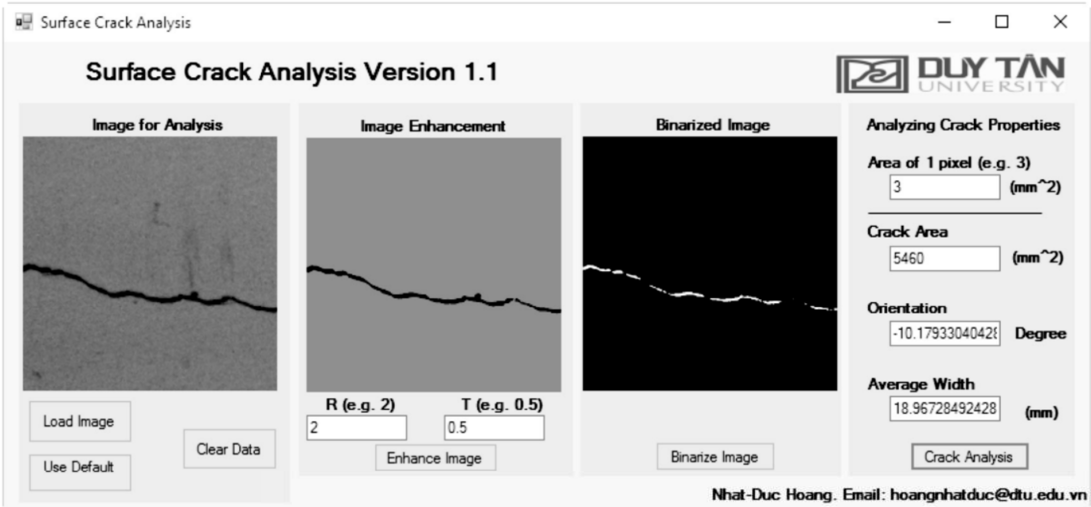

Fig. 4. Analysis result of the testing image number 2

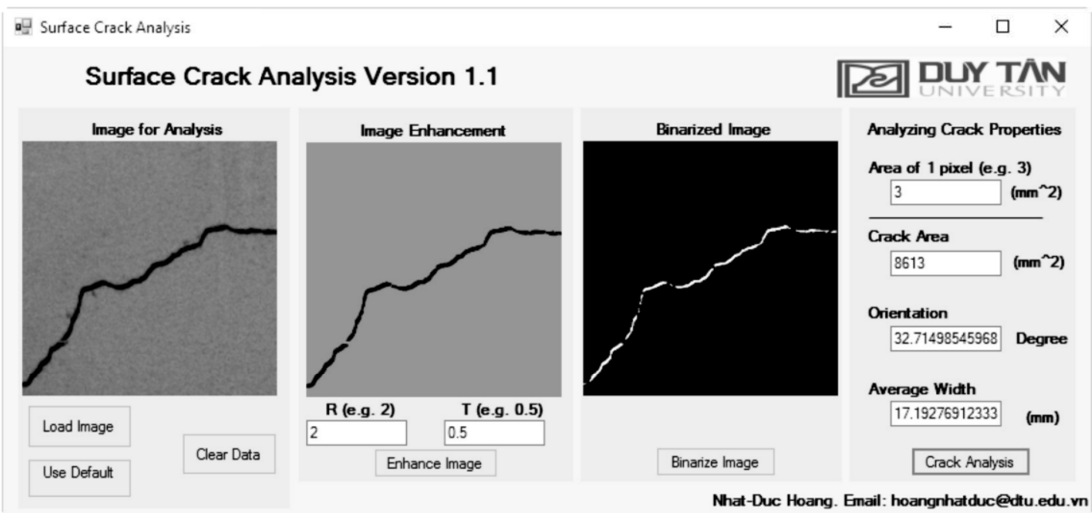

Fig. 5. Analysis result of the testing image number 3

5. Conclusion

This study develops an image processing program, named as Surface Crack Analysis, for detecting crack defects on surface of building structures. The program utilizes an image enhancement algorithm called Min-Max Gray Level Discrimination (M2GLD) as a preprocessing step for enhancing the image quality. The well-known Otsu method is used for image binarization to reveal cracks existing in building surface. The newly constructed program has been developed in Visual C# .NET and is capable of recognizing crack objects and analyzing their characteristics including the area, width, and orientation. The experimental results assert that the cracks in testing images have been identified satisfactorily. Hence, the program can be a potential alternative for building maintenance agency used in the task of building periodical survey.

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