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Long-distance precision inspection method for bridge cracks with image processing

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ABSTRACT

The detection of cracks is the most important step during the inspection of bridge substructures. However, traditional crack detection methods are subjective and expensive. Therefore, crack detection techniques based on image processing have been proposed. In this paper, a long-distance image acquisition device and an integrated image processing method are proposed for precisely extracting cracks. The proposed method consists of three parts. Firstly, general steps for crack extraction are realized which include image clipping, enhancement, smoothing, segmentation, crack marking and rotation. Secondly, the electronic distance measurement algorithm is approved to calculate the crack width in millimeters. Finally, an improved image segmentation algorithm based on C–V model is provided for crack extraction. We evaluate the proposed method on a collection of 1000 bridge images which have been gathered under different conditions. Experimental results show that the modified algorithm could effectively improve the detection precision rate and reduce the running time.

1. Introduction

A crack is one of the earliest signs of structural failure in a bridge. Conventional methods for crack detection are implemented by experienced inspectors who mark the cracks manually and read the width of the cracks with their naked eyes. However, such detection methods are very expensive, time-consuming, dangerous, labor-intensive and subjective [1,2]. Therefore, crack detection methods based on the image processing are desired for acquiring objective and accurate data.

Many researchers have paid attention to bridge crack inspection methods based on image processing. A crack is the sensitive area of a concrete bridge image and it provides the most important information for image segmentation. Because of the non-uniform illumination, contaminated concrete surface, and variations of crack types, image segmentation becomes a stubborn step during crack extraction. Abdel-Qader compared the results of image segmentation algorithms based on wavelet transform, Fourier transform, Sobel and Canny, respectively [3]. Hutchinson proposed a method to extract cracks from the concrete structure images by combining wavelet and Canny transforms [4]. These traditional image segmentation algorithms can completely extract the edge of crack under the condition that illumination is uniform and the image is not affected by noise. Navon also provided an adaptive threshold algorithm to solve the problems of image segmentation [5]. Iyer used a mathematical morphology algorithm for the image segmentation of bridge cracks [6]. Yu designed a crack identification system and applied the Dijkstra algorithm to identify the cracks for pavement tunnels, however, the recognition precision is low [7]. Sinha applied machine vision technology to identify and classify the internal cracks in concrete pipes [8]. Zou provided a pavement crack image segmentation algorithm based on CrackTree that is capable of extracting cracks from pavement images with non-uniform illumination [9]. Je-Keun designed a cantilevered and vehicle-mounted crack detection system for bridge substructures which applied the Canny algorithm to extract cracks. Its crack detection rate can reach 96.7%, and the mean error is less than 0.023 mm [10]. Zhu proposed a crack detection algorithm based on image recognition for post-earthquake buildings, which can extract the length, width and direction of the crack [11]. Yamaguchi and Hashimoto presented a crack recognition algorithm based on percolation on the concrete surface. Their algorithms achieved good image segmentation results and high computation speed [12]. In recent years, the image segmentation methods based on the level set can directly and naturally express the region and border of images. Therefore, these methods correspond more closely to the definition of image segmentation. Furthermore, the results achieved by the level set do not need to do post-processing such as edge join and region merge. Consequently, the level set has become a hot research topic in the field of image segmentation [13,14]. Similarly, the image segmentation algorithm based on the regional active contour model has good segmentation result in object identification which has a useful range of gray levels [15,16]. C–V model can also acquire ideal segmentation results even when the image has a complex background and fuzzy edges. However, the C–V model always assumes that the object and background of the image have respective uniform gray values. Because the surface of a

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concrete bridge is chronically exposed to the outdoor environment, the bridge cracks contain much noise. It is therefore very hard to directly achieve ideal results with the C–V model from an image of the bridge substructure.

In view of the great influence of noise to bridge crack images, in this paper, the C–V model is applied to the image segmentation of bridge cracks. Simultaneously, edge pixels are stored into arrays as C–V model edge pixels. Subsequently, the Canny algorithm is utilized to seek the new edge pixels next to the above C–V model edge pixels. Afterwards, the closed and higher precision edge pixels are obtained. Finally, accurate widths of the cracks are acquired by enforcing image clip, image fill and rotation transformations.

2. Description of the crack inspection system

2.1. Purpose of the bridge inspection

In view of many factors, substructures of bridges are annually inspected for cracks, potholes, leakages and other damages. Among these damages, cracks become the most important feature in deciding the bridge damage degree. Cracks appear and arise as the results of lacking maintenance, contraction due to rapid temperature variation, fluctuation between contraction and expansion due to temperature changes, and extra load from partial ground expansion.

In most cases, bridge inspection is enforced outdoors. Especially beneath a bridge, there is a safety issue for inspectors. Inspectors have to stand on temporary scaffolding in order to observe the safety status of a practical bridge. An industrial accident may occur during erecting the scaffolding, as shown in Fig. 1(a). Besides cost reduction, improvement of the work environment has become one of the main considerations in bridge inspections. For safety reasons, bridge-inspection vehicles are widely used for crack detection, as shown in Fig. 1(b). However, the bridge-inspection vehicles are very expensive and a lane has to be closed for crack detecting. By standing on scaffolding or the bridge-inspection vehicles, inspectors can observe cracks with a microscope at a short range, as shown in Fig. 1(c). After reading the crack information from the microscope, inspectors write and mark the width alongside cracks with a chalk, as shown in Fig. 1(d). With above processes, the crack information is collected, but these processes are labor-intensive, subjective and high-risk.

To satisfy the inspection requirements, the measurement result of the crack width must be accurate to 0.1 mm and the measurement error must be less than 0.05 mm. Moreover, the inspectors can easily get accurate width of cracks far away from 20 m. Furthermore, it's important to note that there is no access to the area under the inspected span (river, highway or railway). For this purpose, a high-precision image acquisition device and image processing software are provided in the following sections.

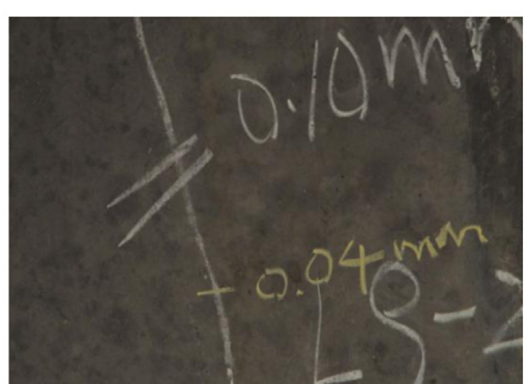
2.2. Crack inspection system configuration

The proposed crack inspection system is composed of an image acquisition device, a mechanical holder, an infrared distance meter, an angular transducer, image processing software, and data storage devices. The system captures and stores images of bridge substructures, measures distance and angle information, enhances the contrast distribution of crack and non-crack areas, minimizes image noise with contourlet transformation, adaptively modulates threshold, clips crack areas, marks crack areas and calculates widths of cracks. The system configuration is shown in Fig. 2.

a) Inspection on the scaffolding

b) Inspection on the vehicle

c) Observation with microscope



d) Mark crack widths with chalks

Fig. 1. Traditional crack inspection methods.