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Recognition and evaluation of bridge cracks with modified active contour model and greedy search-based support vector machine

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ABSTRACT

Concrete cracks are the most important representation for evaluating the bridge health condition and conducting to take appropriate actions to optimize expenditure on maintenance and rehabilitation. In this paper, we develop a fully-automatic machine learning based algorithm for extracting cracks from concrete bridge images, which combines a modified region-based active contour model for image segmentation and the linear support vector machine using greedy search strategy for noise elimination. In practice, the crack detection is a challenging problem because of (1) subtle difference between the cracks and the noises, (2) inconsistent intensity along the cracks, and (3) possible shadow regions with similar intensity to the cracks. To solve these problems, the proposed method consists of three steps. First, we build a high-precision image acquisition framework, which can automatically collect image sequences from the lower bridge slab and fuse the multiple sensor data for computing crack parameters. Second, we develop a modified region-based active contour model combined with the iterated Canny operator for the concrete image segmentation. Finally, we utilize the novel feature selection approach based on the linear support vector machine with a greedy search strategy for noise elimination. After that, we provide a crack width calculation method which combined the binary image with the gray scale image information. We evaluate the proposed method on a collection of 1200 real bridge images, which gathered from 10 existing bridges on various weathers, and the experimental results show that the proposed method achieves a better performance than several up-to-date algorithms.

1. Introduction

Collecting and evaluating the existence, location, and modality of cracks on a concrete structure is crucial to estimate the health status of the bridges. Cracks are usually generated by multiple reasons, e.g., vehicle overload, damage caused by bad weather, road self-aging, corrosion of reinforcement steel bars and severe bearing events. Existence of cracks provides an earliest indication of the degradation inside the concrete structures. By far, bridge crack evaluation is implemented by experienced inspectors. However, manual inspection for surface of cracks is time consuming, labor-intensive, and depending on the inspector's skill and experience. Moreover, for massive bridge structures, manual inspection may be difficult and sometimes dangerous to carry out.

From early proposed approaches based on the image intensity variation, the complexity of image processing methods developed has greatly increased, partly due to the increased computing power. A number of edge detectors are widely used in image processing and most of them specify only a spatial scale for detecting edges [1,4,7]. Latest research activity concerning crack detection concentrates primarily on vision based crack recognition [10,19,27]. Machine learning and image processing have been introduced to improve the efficiency of crack assessment. Based on the machine vision techniques, non-contacting crack detection and recognition become reality [15,21,31]. Accurate and automatic extraction of the crack information becomes particularly important. Chambon provides automatic detection of points of interest inside thin structures in a high-textured background [3]. Oliveira presents a novel framework for automatic crack detection and classification using survey images acquired at high driving speeds. Zou develops CrackTree, a fully-automatic method to detect cracks from pavement images [32]. Important efforts have also been made to reduce the effects of non-uniform light distribution. Moreover, Ying and Salari use a beamlet transform-based technique for filtering the image once it has been homogenized [26]. Tsai illustrates the use of a geodesic minimal path based method for generating the crack map suitable for the path planning process [22]. Valenca introduced an innovative method named MCRACK Image Processing of Cracking in Concrete Surfaces, to automatically detect, map and measure cracking using digital image processing in a fast and reliable way [23]. Yamaguchi proposed an efficient crack detection method using percolation-based image processing and adopted template matching techniques. The percolation process is

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terminated by calculating the circularity during the processing when the focal pixel is regarded as a background pixel [25]. Je-Keun Oh developed a robotic system for bridge inspection for practical use with both automatic inspection mode and manual inspection mode [19]. In addition, this robotic system has been developed for batch processes to write the bridge safety diagnosis reports from the image capturing using robot motion control to the bridge management system. Zalama proposes a novel approach to detect and classify LCs and TCs that use a suitable methodology to generate banks of Gabor filters [28]. Mathavan proposes a new methodology where image texture properties are used in conjunction with an unsupervised learning technique called Kohonen maps for the detection of cracks from 2D road images [17]. Over the past decade, several image processing based crack detection systems have been developed for automatic concrete distress evaluation. However, concrete surface images frequently have various details at different scales.

In this context, the wavelet based multiscale technique can be a candidate to extract edge information from concrete images [11,14]. Wang uses the image segmentation on the principle of the local gray consistency and the road shape features with Dempster-Shafer evidence theory [24]. In recent years, the image segmentation methods based on 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, results achieved by the level set do not need to do post processing such as edge join and region merge [16]. Consequently, the level set has become a hot research topic in the field of image segmentation [14]. Similarly, the image segmentation algorithm based on the regional active contour model has a good segmentation result in object identification, which has a useful range of gray levels [30]. Active contour model can also acquire ideal segmentation results even when the image has a complex background and fuzzy edges [29]. However, the active contour model always assumes that the object and background of the image have respective uniform gray values. Because the surface of a concrete bridge is chronically exposed to the outdoor environment, the bridge cracks contains much noise. It is therefore very hard to directly achieve ideal results with active contour model from an image of the bridge substructure.

Based on many experiment results, due to the non-uniform illumination and contamination on the surface of bridges, there are still various kinds of noises after the image segmentation. Traditional noise elimination methods cannot keep the exact crack edges while reducing noises. For this reason, artificial intelligence and machine learning consist of a number of established methods for image analysis and classification are applied to the problem of noise elimination [8]. And a number of machine learning methods have been applied for crack identification as seen later in this section. Saar has fed image intensity features into the neural network to recognize and classify pavement cracks [20]. Here, the images are either smooth or have large cracks. They report almost 100% accuracy of the algorithm. However, they fail to clearly identify what the accuracy measure is. Na and Tao use the supervised learning algorithm called support vector machines on highly uniform non-texture images and report a 91% classification accuracy [18]. Farhidzadeh proposes a pattern classifier technique titled support vector machines for the fracture mode identification in cementitious materials [6]. In addition, other methods, such as pulse-coupled neural networks, have also been employed for crack detection.

The main research question addressed in this paper is the detection of cracks inside homogenous bridge surfaces with heavy noises. We assume that the original bridge images are in grayscale and contain noises such as shadows and stains. Many image processing algorithms mistake the noises for cracks. This false detection is because noises are usually associated with the change of color and intensity locally, and these changes are present as subtle edges and lines in the images. For this, we propose a modified algorithm for reducing the computation cost of the active contour based image segmentation algorithm while preserving the accuracy of crack extraction. And we recommend the use of support vector machine explicitly in the noise elimination algorithm. By combining it with greedy search strategy, a novel detection methodology for cracks is proposed, whereby the algorithm also incorporates the knowledge of a skilled person for an efficient and consistent detection of cracks.

This paper is organized as follows. In Section 2, we present an integrated high-precision image acquisition device and the whole process of the automatic crack recognition algorithm. The modified region-based active contour model for concrete image segmentation to achieve the desired efficiency and speeding-up is described in Section 3. Section 4 discusses the feature selection and noise elimination algorithm based on the support vector machine. Section 5 shows a crack width calculation method which combined binary image with gray scale image. In Section 6, we compare the performance of the proposed method with the novel level set and three other state of the art crack extraction algorithms and show experimental results about computation times for applying crack detection in large images and about the accuracy of crack detection. We also provide an integrated crack extraction software development, which can effectively improve our image processing speed. Finally, the conclusions are presented in Section 7.

2. Automatic crack detection framework

The proposed crack detection framework is to automatically collect image sequence of the lower bridge's surface and fuse multiple sensors for extracting cracks. The utilized crack detection system is composed of a whole set of real time integrated image acquisition devices and the automatic crack recognition algorithms, as shown in Fig. 1.

2.1. High-precision image acquisition device

The proposed high-precision image acquisition device consists of a digital single lens reflex camera, a telephoto lens with 500 mm focal length connecting with a 2× teleconverter, a flash lamp and an autofocus controlling apparatus. For acquiring the distance and shooting angle information, a feedback laser diastimeter and an angular transducer are integrated on a mechanical holder with the above image acquisition devices, as shown in Fig. 2. Moreover, a laptop is connected to store image sequences, distance and angle information. For convenience, a database table is applied to timely save these various kinds of data. Synchronously, the laptop allows the camera to be focused and controlled by an infrared remote-control unit.

2.2. Automatic crack recognition algorithm

On the other hand, the entire automatic crack recognition algorithms for detecting cracks from the captured images are sequentially presented as shown in Fig. 3. Generally, after capturing the crack images, the pre-processing for the image enhancement is implemented by using the median filters. To achieve high calculation speed, the Canny operator is utilized to initialize the active contour. Then the image segmentation algorithm based on the modified region-based active contour model is carried out to extract the edge of cracks. Next, the support vector machine based on the greedy search is utilized for precisely eliminating noises and keeping the edge of cracks. Finally, we use the contour tracing algorithm to mark every crack and compute the crack parameters. More detailed explanations will be given in the following sections step by step.

Subsequently, we develop the proposed crack extraction software to compute the crack parameters from the segmented images. Our program can extract the crack widths with 0.1 mm precision, and the measurement error is <0.03 mm. The automatic crack inspection system can help determining whether the maintenance is needed.

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