ARTICLE IN PRESS

AUTCON-02136; No of Pages 9

Automation in Construction xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

A self organizing map optimization based image recognition and processing model for bridge crack inspection

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ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 25 July 2016
Accepted 19 August 2016
Available online xxxx

Keywords:
Self organizing map optimization
Image recognition
Bridge inspection

ABSTRACT

The current deterioration inspection method for bridges heavily depends on human recognition, which is time consuming and subjective. This research adopts Self Organizing Map Optimization (SOMO) integrated with image processing techniques to develop a crack recognition model for bridge inspection. Bridge crack data from 216 images was collected from the database of the Taiwan Bridge Management System (TBMS), which provides detailed information on the condition of bridges. This study selected 40 out of 216 images to be used as training and testing datasets. A case study on the developed model implementation is also conducted in the severely damage Hsichou Bridge in Taiwan. The recognition results achieved high accuracy rates of 89% for crack recognition and 91% for non-crack recognition. This model demonstrates the feasibility of accurate computerized recognition for crack inspection in bridge management.

1. Introduction

In 2009, Typhoon Morakot wrought catastrophic damage on Taiwan, leaving 461 people dead and 192 others missing, with a cost of roughly 110 billion New Taiwan dollars (NTD), which is close to 3.3 billion United States dollars (USD) in damages. The extreme amount of rain triggered enormous mudslides and flooding throughout southern Taiwan. Typhoon Morakot not only tested how the Taiwan government could relieve the victims of a severe disaster, but also drew attention to the need to improve the safety of infrastructure to reduce the impact of disasters. There are over twenty thousand bridges located across Taiwan. As bridges have an important role in facilitating transportation, damage to bridges by disasters not only threatens the safety of users, but can also disrupt traffic flows and cause residents to be locked in place.

Cracking in concrete bridges is an inevitable problem resulting from natural processes and can invite spectacular failure of the entire bridge. Cracks not only provide access to harmful and corrosive chemicals inside concrete, but also allow water and deicing salts to penetrate through bridge decks, which can damage superstructures and bridge esthetics. Routine inspections are widely adopted and are carried out manually by certified bridge inspectors every two years, as stipulated in the National Bridge Inspection Standard by Federal Highway Administration (FHWA) in USA. Inspection results are mainly based on the inspectors' observations and visual assessment [1,2]. However, such bridge detection methods have several limitations. The inspection process is laborious, time-consuming, and influenced by the subjective behavior of individual inspectors. The visual inspection only provides qualitative information on defects. Moreover, finding experienced bridge inspectors poses a challenge for the construction industry, which is now facing a pressing shortage of experienced and highly trained inspection personnel [2,3].

In order to overcome these issues, considerable research has been conducted in an effort to develop automated bridge crack inspection tools to reduce the field work required for inspectors [4]. For example, Oh et al. suggest certain image processing algorithms for detecting and tracing cracks combined with the use of a robot mechanism [5]. Zhu et al. propose an automated bridge condition assessment system with a focus on detecting large-scale bridge concrete columns [6]. Yu et al. designed a robot which can detect fissures underneath a bridge. They provided a safe and effective machine vision technology to detect the bridge [7]. Bu et al. developed an automatic bridge inspection approach by employing Support Vector Machines to classify cracks based on wavelet-based image features. The researchers tested 50 different image samples, and both 'complex' and 'normal' images were considered. The resulting recognition accuracy rates of the crack ranged from 74% to 93.26%, varying according to the different image types, training set types, and the feature extraction methods used [8]. Li et al. also put forward a method consisting of crack extraction, an electronic distance measurement algorithm, and an image segmentation algorithm to detect cracks [3]. Further increasing the reliability and accuracy of the

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http://dx.doi.org/10.1016/j.autcon.2016.08.033
0926-5805/

results remains an ongoing effort in this research area. The algorithm and the restricted conditions employed in this study contribute to this effort to improve crack detection. The objective of this study is to develop an automatic bridge crack detection method based on self-organizing map optimization through image processing technology. Several stages of image recognition for bridge cracks are utilized to process 216 images of randomly selected bridges located in northern Taiwan. The model presented here can improve the accuracy of bridge crack inspections and reduce the cost of labor.

2. Bridge crack inspection

Degradation often occurs during the final stage of reinforcement concrete structures' life cycle. The various degrees of maintenance and service conditions of structures in different natural environments derive from disparate degradation rates and consequences. In Taiwan, bridges very easily deteriorate due to high humidity, frequent earthquake loading, and overloading by heavy vehicles [9]. The acceleration of degradation in reinforced concrete structures can be attributed to natural factors and human factors. The natural factors causing cracks in and damage to the structures mainly include strong winds, storm erosion, earthquakes, flooding, and other force majeure, while human factors may be the improper or wrong use of the structures, such as vehicle overload and irregular maintenance. The cracks on surfaces often show the initial fatigue reaction of the bridge components and forecast the failure of reinforced concrete structures [10]. Once the crack emerges, the degradation of the entire structure will follow in a short time, reducing in the overall strength and durability of the structure. Thus, in order to extend the service life of concrete structures, timely monitoring and remedial management are extremely necessary to avoid more serious deterioration.

Current bridge crack inspection systems, implementation methods, and rating records for detection vary among countries all over the world. The Federal Highway Administration (FHWA) specifies four condition states to evaluate the elements of a bridge: Good, Fair, Poor, and Severe [1], and also employs a scale of 0–9 and NA to rate the National Bridge Inventory (NBI) conditions [2]. The Japan Highway Public Corporation classifies the performance degradation of bridge elements as I, II, III and IV [11]. However, the degradation level should be considered first before rating. For instance, when a crack exists in components, the crack shape, amplitude, and interval are key aspects that should be evaluated to assign more accurate ratings. A standardized bridge inspection system has not yet been formulated in Taiwan. However, local bridge authorities have developed their distinctive and practical assessment criteria and rating record modes.

In Taiwan, the predominant nondestructive evaluation method currently employed is visual inspection conducted by professional inspectors, with its relative advantages in cost and speed. The DERU evaluating method is a visual inspection assessment approach to bridge management developed by the Taiwan Area National Freeway Bureau, which divides component degradation into the degree of degradation (Degree), the scope of degradation (Extend), the importance of the degradation phenomenon to components (Relevancy) and maintenance urgency (Urgency) four parts with employing 4 levels (shown in Table 1) to evaluate [9]. The DERU criterion enables bridges to be evaluated in as short a time as possible, which greatly enhances inspection efficiency. However, visual inspection to a great extent relies on the naked-eye observation of the component appearance to judge the degradation degree and scope. Or in other words, this method completely depends on the subjective evaluation of the inspector. Considering the number of bridges in total, the increasing number of bridges damaged by natural disasters in Taiwan in particular, the manpower shortage affecting related bridge management institutions, and the difficulty in training learners with relevant professional knowledge, carrying out regular, effective bridge inspections has become an enormous challenge. Especially after serious natural disasters, the workload of inspectors is even more onerous. Thus, the results of visual inspection are quite biased due to the different inspecting habits of individuals, and often have questionable reliability.

3. Data collection

This research employs a digital camera to capture concrete bridge cracks in order to develop an image recognition program and process image identification. Before shooting, the choice of the bridges included in the sample for the present study was based on the DERU visual inspection results. Ten concrete bridges in northern Taiwan are selected, and the crack images were randomly chosen from the artificial field shooting database. According to the manual of highway maintenance which was published by the Taiwan Highway Administration, routine highway maintenance needs to be conducted every two years [12]. Thus the bridges that have been maintained recently were filtered out from this research. According to the DERU bridge detection assessment criteria issued by the Join Engineering Consultants, when the D value is >2 (degree value refers to the severity degree of bridge degradation, from grade 1 to grade 4), the damage intensity will be visible in appearance and maintenance is needed.

The training samples used to research and develop the image recognition system of this study are the close-range images of concrete bridge cracks documented by the handheld digital cameras. Field environmental conditions must be taken into careful consideration when shooting onsite to obtain the images for training purposes. Since image processing is necessary before recognition, greater uniformity and consistency of the image acquisition conditions is desired to avoid errors in the image processing. The intensity of illumination in shooting is the major element influencing the digital camera photos. Changes in the sun position give rise to a variety of natural illuminations at each time point. Additionally, the intensities of illumination generated by natural light and artificial light are entirely different, specifically the illumination intensity of artificial light is more than that of natural light by several-fold.

Generally speaking, due to the light and shadow, the color of a concrete structure crack is deeper and darker compared to the color of the surrounding surface. Natural light and auxiliary light is critical in affecting the black shadow area of the cracks, as well as reflected light sources on the concrete surfaces, all impacting the system recognition results. Because of the uncontrollability of the climate, seasons, and time with respect to the nature light in the field, more easily controlled artificial lighting is employed to assist with shooting. In order to reduce the effects of natural light in this study, a natural light shield was applied to completely eliminate the uncontrolled factors of natural light. Setting the camera flash and fixing the shooting angle play a significant role in standardizing the artificial light source. Thus the taking lens was

Table 1
DERU Rating System criteria.

	0	1	2	3	4
D	Not applicable	Good	Fair	Poor	Severe
E	Not applicable	<10% < 30% < 60% <			
R	Not applicable	Marginal	Small	Medium	Large
U	Not applicable	Routine maintenance	3 years	1 year	Urgent maintenance

Please cite this article as: J.-H. Chen, et al., A self organizing map optimization based image recognition and processing model for bridge crack inspection, Automation in Construction (2016), http://dx.doi.org/10.1016/j.autcon.2016.08.033