DAMAGE ASSESSMENT OF REINFORCED CONCRETE BRIDGE DECKS USING TAM NETWORK

Hitoshi Furuta[1], **Hiroshi Hattori**[2] **and Dan M. Frangopol**[3]
[1]*Department of Informatics, Kansai University, Takatsuki 569-1095, Japan*
E-mail: furuta@res.kutc.kansai-u.ac.jp
[2]*Graduate School of Informatics, Kansai University, Takatsuki 569-1095, Japan*
[3]*Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, CO 80309-0428, USA*

Abstract

In order to establish a rational management program for bridge structures, it is necessary to evaluate the structural damage of existing bridges in a quantitative manner. However, it is difficult to avoid the subjectivity of inspectors when visual data are used for the evaluation of damage or deterioration. In this paper, an attempt is made to develop an optimal bridge maintenance system by using a health monitoring technique. The damage of Reinforced Concrete (RC) bridge decks is evaluated with the aid of digital photos and pattern recognition. So far, neural networks have been applied to judge the damage state of RC bridge decks. However, there are still some problems that learning data are not enough and recognition accuracy is not satisfactory. In order to solve these problems, TAM network is applied here, which is an optical system. Though the numerical examples using actual data, it is shown that the recognition rate is increased.

Keywords: damage assessment, RC slab, pattern recognition, TAM network

Introduction

In order to establish a rational management program for bridge structures, it is necessary to collect enough data about the material and structural characteristics and to evaluate the structural damage of existing bridges in a quantitative manner. However, it is often seen to lose the drawings or design specifications. Moreover, it is difficult to avoid the subjectivity of inspectors when visual data are used for the evaluation of damage or deterioration. In this paper, an attempt is made to develop a new system that can evaluate the damage condition of existing structures by using the visual information given by digital photos (Furuta et al., 2004a). The proposed system is based upon such new technologies as image processing, photogrammetry, pattern recognition, and artificial intelligence (Furuta et al., 2004b). The damage of Reinforced Concrete (RC) bridge decks is evaluated with the aid of digital photos and pattern recognition. Using the proposed system, it is possible to automatically evaluate the damage degree of RC bridge decks and therefore avoid the subjectivity of inspectors. Several numerical examples are presented to demonstrate the applicability of the proposed system.

Damage Evaluation of RC Deck by Pattern Recognition

In this study, the damage of Reinforced Concrete (RC) bridge decks is evaluated with the aid of digital photos and pattern recognition (Gonzales and Woods, 2002; Yagi, 2000). In general, the procedure for extracting the characteristics of cracks showing up on concrete decks through digital images and classification based on the damage levels are used in the typical pattern recognition system. Figure 1 shows the procedure of such a pattern recognition system. First, the input data to

M. Pandey et al. (eds), Advances in Engineering Structures, Mechanics & Construction, 81–86

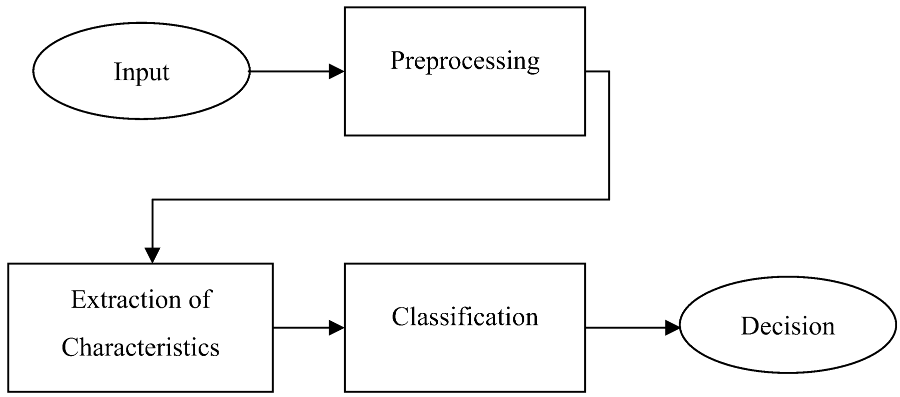


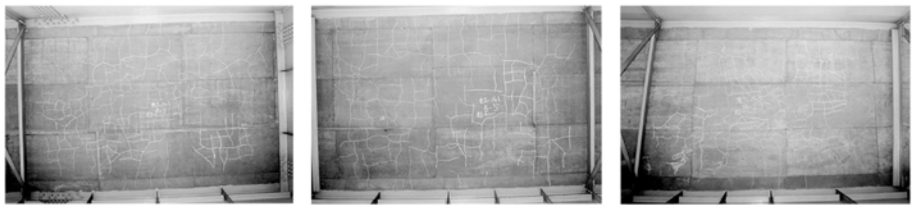
Fig. 1. The procedure of pattern recognition system.

this system consists of the digital images of the concrete decks taken by a digital camera. Next, the linear pattern of cracks is extracted from the digital images of the concrete decks through image processing techniques. Moreover, the characteristics of cracks such as the projection histograms are extracted. Finally, the digital images of cracks are classified into different damage levels based on the extracted characteristics through the TAM (Topographic Attentive Mapping) network (Seul, 2001).

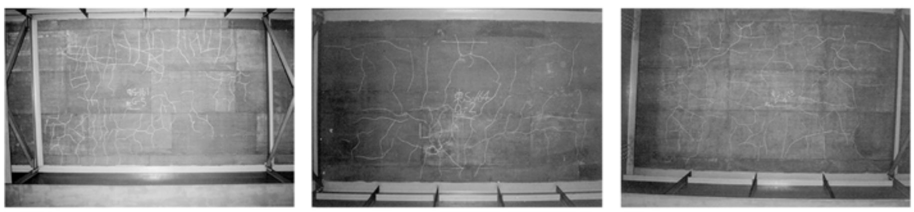
To obtain the test material, digital images of concrete decks taken by a digital camera are used. If input data that can be acquired in low resolution and by using common digital camera is used, the costs for the assessment of integrity can be reduced and input data can be acquired easily. The total number of digital images is 47 and each image is scanned with the resolution of 360 pixels per inch in both directions. In this resolution, each image is normalized to the 768 $\times$ 480 pixel rectangle and converted to greyscale image. The digital images used in this study are obtained by marking the cracks with white chalk. The damage levels for all digital images are classified into three categories by an expert. Some examples for each damage level are shown in Figure 2.

Cracks in a digital image of concrete deck are detected in accordance with the following procedure: First, the digital image undergoes geometric transformation to extract a rectangular part containing a crack zone. The binarization is a method for transforming greyscale image pixels into either black or white pixels by selecting a threshold. Because the crack zone existed in only a small part of digital image, and also the brightness is not uniform through the crack zone due to the uneven lighting, the extracted rectangular part is divided into smaller blocks. The method proposed by Ohtsu (Yagi, 2000) is applied to the block unit to determine the threshold for binary-coding processing. Then, each block is divided into sub-blocks and the binary-coding processing is applied to each sub-block. These binary images are reduced some noise such as spots and holes after the binary-coding processing. The aim of thinning processing is to reduce the crack zone pixels to lines one pixel width. The crack pattern can be easily recognized by such a thinning processing. Finally, the smoothing processing such as the reduction of insufficient points and the addition of missing line is implemented. After all of these processing, the crack pattern is obtained and used for extracting the characteristics of digital images. The procedure is shown in Figure 3.

In this study, characteristics are extracted based on four criteria; continuity, concentration, directionality (unidirectional or bi-directional), and types (hexagonal or linear) of cracks. The crack pattern of thin lines can be considered a set of directional linear elements and hence characteristics extraction by the projection histogram (Seul, 2001; Sakai, 2002; Duda et al., 2001) would be effective. Because the characteristics of projection histogram of a crack pattern provide information



(a) Images of damage level I



(b) Images of damage level II

(c) Images of damage level III

Fig. 2. Examples of images associated with different damage levels in concrete decks.

on the positions and the quantities of cracks, they can be used as the quantitative characteristics representing the continuity and the concentration of cracks, for the classification of crack patterns. The histograms projected on two directions are computed for extracting a crack pattern; one is the horizontal direction and the other is the vertical direction. The projection histograms are data structures used to count the number of crack pixels when the image is projected on the vertical and horizontal axes.

The characteristic values in each dimension are the number of crack pixels in row for the horizontal histogram, in column for the vertical histogram, and are the quantum numbers in accordance with the dimensionality of characteristics vectors. Figure 4 shows an example of horizontal and vertical projection histograms extracted from a crack pattern.

TAM Network

TAM network (Hayashi et al., 2003) is a one of the neural network and it is modeled from the primary visual area to prestriate cortex. TAM network has four layers; input layer, undimensional basis layer, category layer and output layer. Figure 5 shows the structure of TAM network.

TAM network is available at image of pattern recognition problem because TAM network is a modeled vision system.

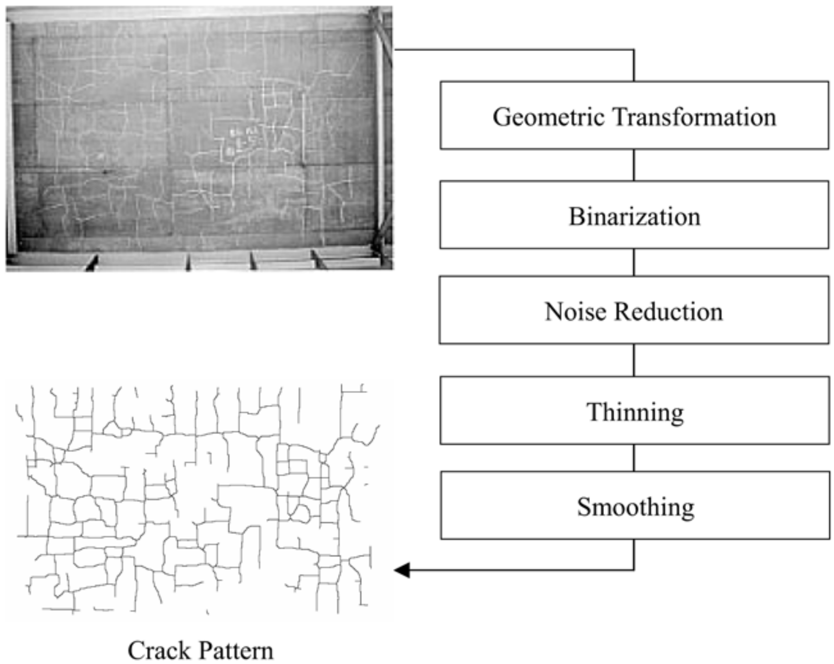


Fig. 3. Procedure of image pre-processing.

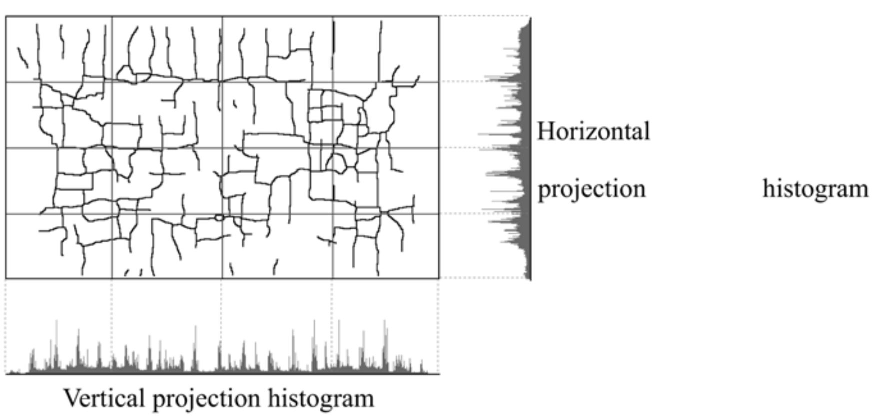


Fig. 4. Example of horizontal/vertical projection histograms extracted from a crack pattern.

Experimental Results

The classification of the digital images of cracks is implemented by using the TAM network. Twenty images of cracks are used for learning of TAM network and the remaining 27 images are used for evaluating the classification results. This implementation is repeated many times by changing the learning data every times. In this learning stage, three damage levels judged by an expert for each image are used as the teaching signal. Also, the teaching data include the same number of each damage levels data. In this numerical example, it is evaluated by the recognition rate of non-learning data, and by comparing with the neural network, the effectiveness is examined. The used learning

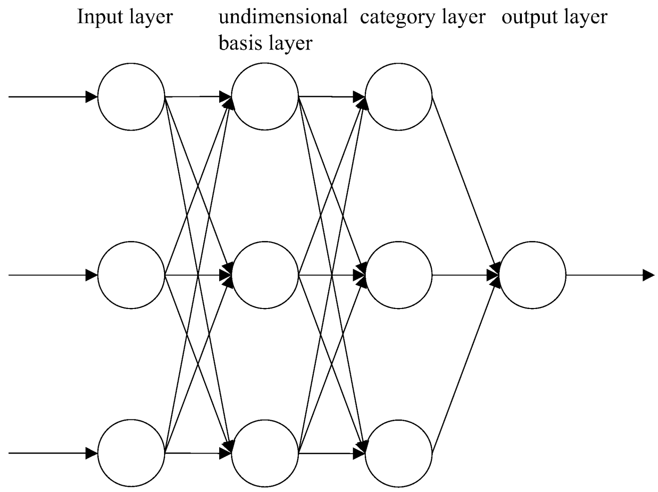


Fig. 5. Structure of TAM network.

Table 1. Learning parameters.

Learning factor	0.3
Learning time	100,000

parameters of TAM network and neural network are shown Table 1. In this research, the digital image is divided to 256 blocks, and detected the element of directionally.

The learning parameter is the same as the neural network to compare the performance. Table 2 shows the classification results with the distribution of directionality. This result is average of all trials.

Only about 70% recognition accuracy is obtained by using neural network. Especially, the recognition rate of B rank is very low (38.5%). It is caused that same digital image of B rank are close to the A rank or C rank. So, recognition rate of B rank is low. On the other hand, by using TAM network, over 90% recognition accuracy is obtained and the recognition rata of all rank are over 90%. Mainly, the recognition rate of B rank is improvement. From this result, a TAM network can recognize the complex problem that a neural network cannot recognize. It is considered that the proposed system can recognize similar digital image by using TAM network that is modeled ocular system.

Table 2. Recognition accuracy.

Method	Recognition accuracy (%)			
	A (10 entries)	B (13 entries)	C (24 entries)	TOTAL
Neural network	60.0	38.5	87.5	68.1
TAM network	90.0	92.3	95.8	93.6

Conclusions

In this paper, an attempt was made to develop a new system that evaluates the damage condition of existing structures by using the visual information given by digital photos. The proposed system is based upon such new technologies as image processing, pattern recognition, and artificial intelligence. A new measuring system was developed by using two digital cameras. Moreover, the system for extracting the characteristics of cracks showing up on concrete slabs through digital images was developed and classification based on damage levels was attempted by using these results. First, the linear pattern of cracks is extracted from the digital images of the concrete slabs through image processing techniques. Next, the characteristics such as the projection histograms that are often applied in the field of optical character recognition, and the feature points in the border expression are extracted. Finally, the digital images of cracks are classified into different damage levels based on the extracted characteristics through TAM (Topographic Attentive Mapping) system.

References

Duda, R.O., Hart, P.E. and Stork, D.G., 2001, *Pattern Recognition*, A Wiley-Interscience Publication.

Furuta, H., Hirokane, M., Dogaki, M. and Frangopol, D.M., 2004a, Optimal bridge maintenance using health monitoring, in *Proceedings of the Second European Workshop on Structural Health Monitoring*, Munich, Germany, July.

Furuta, H., Hirokane, M., Tanaka, S., Muraki, H. and Frangopol, D.M., 2004b, Bridge management system using digital photos, in *Proceedings of the Second International Workshop on Structural Health Monitoring of Innovative Civil Engineering Structures*, Winnipeg, Canada, September.

Gonzales, R. and Woods, R., 2002, *Digital Image Processing*, Prentice Hall.

Hayashi, I. and Maeda H., 2003, A formulation of fuzzy TAM network with gabor type receptive fields, in *Proceedings of International Symposium on Advanced Intelligent Systems*.

Sakai, K., 2002, *Introduction to Digital Image Processing*, CQ Publication [in Japanese].

Seul, M., O'Gorman, L. and Sammon, M., 2001, *Practical Algorithms for Image Analysis*, Cambridge University Press.

Yagi, N., 2000, *Digital Image Processing*, Ohmsha, pp. 55–60 [in Japanese].