An Intelligent Method for Crack Classification in Concrete Structures Based on Deep Neural Networks

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ABSTRACT

Identifying and examining the types of cracks in concrete structures is one of the challenging engineering issues. Detection of crack bifurcation is very important because it detects high intensity surfaces in concrete structures. In this paper, a new architecture based on convolutional neural networks is presented for crack classification in concrete structures. The proposed architecture detected and classified crack bifurcation in less time and higher accuracy than other conventional and authentic deep learning architectures. In this paper, the cracks in 12000 images of concrete structures were investigated by the proposed algorithm, which resulted in 99.3% accuracy in categorizing as non-cracked images, images with simple cracks and bifurcated crack images. Moreover, the analysis of the confusion matrix showed an accuracy of 99.3% and a recall of 99.5%, which confirmed the proper performance of the proposed algorithm. The sensitivity analysis of the proposed algorithm also showed the need for proportionality between the number of data, the number of neurons in the fully connected layer, execution time, and the expected percentage of accuracy according to the application of the problem.

KEYWORDS

Cracks, Concrete Structures, Machine Learning, Deep Learning, Convolutional Neutral Networks.

1. INTRODUCTION

Cracks in concrete structures such as bridges, dams, and skyscrapers are one of the main indicators of durability and possible structural damage [1-6]. Most developed countries carry out regular cracks assessment in concrete structures as part of infrastructure maintenance [6]. These unavoidable issues lead to a great deal of research into the health status of concrete structures [7-9]. Visual inspection is the most common method used to obtain cracking information such as presence, location, thickness, etc. to prepare maintenance programs. Although cracking information can be obtained from a visual inspection, this method is time consuming and often unreliable; therefore, the results depend on the experience and skills of the relevant expert force. Visual inspection is also not possible in high-rise structures. To overcome the disadvantages of visual inspection, image processing and machine learning algorithms have been introduced as a promising alternative method for detecting and monitoring of cracks [10]. One of the damages that its detection could prevent possible future damage to concrete structures is the crack bifurcation. If the crack splits into two or more new cracks at the change of direction, this point is called the crack bifurcation [11]. In this research, in a classification system, crack bifurcation in concrete structures is detected and classified. The innovation of this research can be mentioned in two cases:

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1. The proposed architecture of this paper is a combination of different deep layers that has led to a unique structure.
2. Although some previous studies have examined, detected and classified cracks in concrete structures [6, 12-14], detection of crack bifurcation has received less attention [11]. In some articles, the purpose of which was only to detect cracks (and not to classify some specific types of it), crack bifurcation is also considered, but they have not classified the crack bifurcation as a specific type [14]. Therefore, in this research, crack bifurcation is detected and classified in concrete structures.

The achievements of this research are as follows:

1. Achieving 99.3% accuracy that is a high accuracy in classifying cracks compared to other methods;
2. Relatively low execution time of the proposed architecture (76 min) compared to other valid architectures in deep learning on the same hardware platform.

2. METHODOLOGY

The proposed method of this paper for detecting and classifying cracks in concrete structures according to the block diagram of Fig. 1 is that first in the data collection stage, a video of the concrete structure is prepared by a quad copter. The saved video is then converted to a panoramic image of the concrete structure. In the next step, the panoramic image is decomposed into small images with the desired resolution. After the data collection step, pre-processing is done to remove possible noise and adjust the color intensity of the images. Finally, by designing a deep learning network, the images extracted from concrete structures are classified into three categories. Fig. 2 also shows the proposed architecture of this research. In this architecture, maximum integration was used across the network to maintain the best features. Moreover, after the convolution layer packet normalization is located in the first and second blocks. There is a Relu nonlinear activator function in the first three blocks of the proposed architecture [15]. At the end of the network and in the fourth block, two fully connected layers have been used. To prevent over-fitting, a random removal layer is used between fully connected layers to reduce parameters. In the last layer, the Softmax function is considered for classification as well [16].

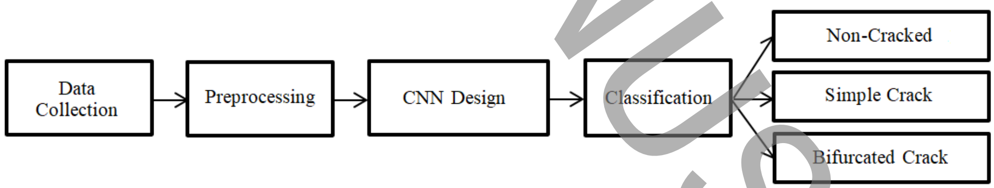

Fig.1: Proposed block diagram for crack image classification

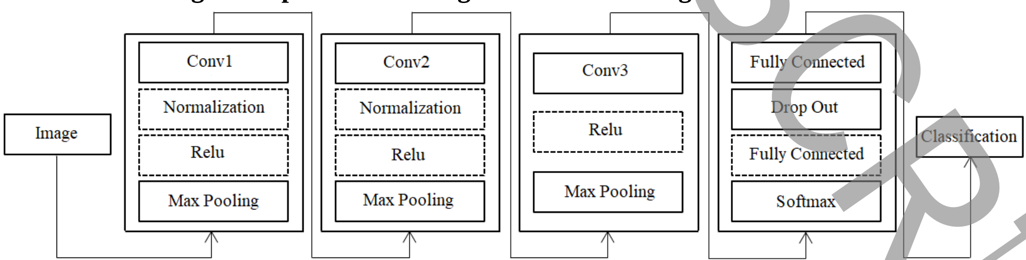

Fig.2: The proposed architecture

3. RESULTS AND DISCUSSION

The confusion matrix for the proposed algorithm of this research is shown in Table 1. As can be deduced from this table, the proposed algorithm has been able to detect the presence of bifurcated crack images of concrete structures in 99.5% of cases. Also, according to this table, the accuracy, precision and call of the proposed algorithm are 99.3, 99.3 and 99.5%, respectively.

Table 1: The confusion matrix for the proposed algorithm

Actual \ Predicted	Non-Cracked	Simple Crack	Bifurcated Crack
Non-Cracked	0.993	0.006	0.001
Simple Crack	0.003	0.991	0.006
Bifurcated Crack	0.001	0.004	0.995

Generally, the convolutional neural networks require large volumes of labeled data. Of course, it is not always possible to provide a lot of labeled data, and in many cases, this has limitations. Although high-tagged data can increase accuracy, it increases computation time and can overshadow the online nature of the learning algorithm. Therefore, the relationship between the number of data and the execution time of the program as well as the desired accuracy is a challenge that can vary depending on the subject under study. Sensitivity analysis of the number of data in the proposed algorithm showed that although the execution time of the algorithm decreases with decreasing the number of data, the percentage of accuracy also decreases, which confirms the challenge of proportionality between the number of data, execution time, and expected percentage of accuracy. However, at least 10,000 data results in a good accuracy of over 90% and an approximate time of 62 minutes.

4. Conclusion

According to the intelligent method presented in this paper, the images extracted from the flying robot, which can cover all parts of a concrete structure, were classified by a proposed deep architecture. This classification included categories of non-cracked images, images with simple cracks, and bifurcated crack images, which yielded 99.3% accuracy. The strengths of this paper can be summarized in four cases: first, the proposed deep architecture is much less complex than other deep architectures, and secondly, it simply leads to higher accuracy than the other methods introduced in the previous studies and other deep architectures have been validated. The third case involves less execution time than other methods. The fourth and final advantage of this article is the detection of crack bifurcation, which has received less attention in other articles. Although the proposed method may not be suitable for being online due to runtime, the use of a strong hardware system could help to realize this idea. Besides, the use of flying robots, in addition to the advantage of quad copter, can be useful and effective in the online investigation of crack bifurcation and other important cracks in concrete structures.

5. References

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