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Comparison of deep convolutional neural networks and edge detectors for image-based crack detection in concrete

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HIGHLIGHTS

- Investigating the performance of six edge detectors for concrete crack detection.
- Studying the performance of a DCNN trained in three modes to detect the same cracks.
- Comprehensive comparison between the edge detectors and the DCNNs.
- Proposing a new hybrid crack detector by combining the DCNN and the edge detector.
- The hybrid method had 24 times less noise than the least noisy edge detector.

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ABSTRACT

This paper compares the performance of common edge detectors and deep convolutional neural networks (DCNN) for image-based crack detection in concrete structures. A dataset of 19 high definition images (3420 sub-images, 319 with cracks and 3101 without) of concrete is analyzed using six common edge detection schemes (Roberts, Prewitt, Sobel, Laplacian of Gaussian, Butterworth, and Gaussian) and using the AlexNet DCNN architecture in fully trained, transfer learning, and classifier modes. The relative performance of each crack detection method is compared here for the first time on a single dataset. Edge detection methods accurately detected 53–79% of cracked pixels, but they produced residual noise in the final binary images. The best of these methods was useful in detecting cracks wider than 0.1 mm. DCNNs were used to label images, and accurately labeled them with 99% accuracy. In transfer learning mode, the network accurately detected about 86% of cracked images. DCNNs also detected much finer cracks than edge detection methods. In fully trained and classifier modes, the network detected cracks wider than 0.08 mm; in transfer learning mode, the network was able to detect cracks wider than 0.04 mm. Computational times for DCNN are shorter than the most efficient edge detection algorithms, not considering the training process. These results show significant promise for future adoption of DCNN methods for image-based damage detection in concrete. To reduce the residual noise, a hybrid method was proposed by combining the DCNN and edge detectors which reduced the noise by a factor of 24.

1. Introduction

At least a third of the more than 600,000 bridges in the United States include a concrete superstructure or wearing surface [1]. Routine inspections of concrete bridges are conducted periodically to assess overall condition and to identify surface cracking or other degradation [2]. Manned inspections of this type are costly, time consuming, and labor intensive [3–5]. Unmanned and autonomous inspections are a potentially viable alternative to manned inspections [5–10]. Inspections performed by robots or unmanned aerial systems (UAS) are typically image-based, meaning that the inspection platform takes images that are then processed and/or reviewed by an inspector. Previous literature demonstrates several successful applications of image-based inspections to detect cracks [11,12], spalls [13,14], delaminations [14–16], and corrosion [17] in concrete bridges.

Image-based inspections of this type can be performed in three general ways: Raw image inspection, image enhancement, or autonomous image processing. Raw image inspection means that the inspector views the images taken during the inspection

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without any additional processing [5,18]. The number of images collected depends on a number of factors, but is commonly in the hundreds of thousands [5,18]. Manual identification of flaws in such large images sets is time consuming and prone to inaccuracy due to inspector fatigue or human error. Enhanced image inspection refers to the use of some image processing algorithm to make it easier to identify flaws in inspection images. This is typically performed using one of several edge detection algorithms, which greatly magnify the visibility of cracks within images. In doing so, the aforementioned problems with inspector fatigue can be mitigated to some degree. Finally, autonomous image processing refers to the use of an algorithm that detects cracks within images. This is typically accomplished using machine learning algorithms or other artificial intelligence schemes.

This paper discusses the latter two approaches and compares their performance. Image enhancement methods includes the application of a variety of image processing techniques on visual images to detect cracks including but not limited to morphological operations [19], digital image correlation [20,21], image binarization [22,23], percolation model [24], wavelet transforms [25], fractal analysis [28] and edge detectors [12,27,29,31–35]. The autonomous approach for crack detection on the other hand requires a set of training images to learn the features of cracks. Similarly, several researchers have shown the feasibility of autonomous crack detection in visual images using combined image processing techniques and artificial neural networks [30,37]. Deep convolutional neural networks (DCNNs) have been recently used for concrete crack detection [38–40].

Despite the abundance of image-based crack detection studies, direct comparisons between these methods is a gap. Save two noteworthy exceptions, most research focuses on developing new methods for crack detection rather than comparing the performance of existing methods. Abdel-Qader et al. [27] compared the performance of the fast Haar transform, Fourier transform, Sobel filter, and Canny filter for crack detection in 25 images of defected concrete and 25 images of sound concrete. The fast Haar transform was the most accurate method, with overall accuracy of 86%, followed by the Canny filter (76%), Sobel filter (68%), and the Fourier transform (64%). he processing time was not considered in the analysis and the criteria for recoding true of false positives in the binary images were not clear. Lack of definition for metrics such as true positive has seen in the past studies. Mohan and Poobal [41] reviewed a number of edge detection techniques for visual, thermal, and ultrasonic images, but the information presented was from several studies that considered vastly different data sets, and so the results are not directly comparable. A comparison between two edge detectors, Canny and Sobel, and a convolutional neural network is done in [39]. However, the comparison was

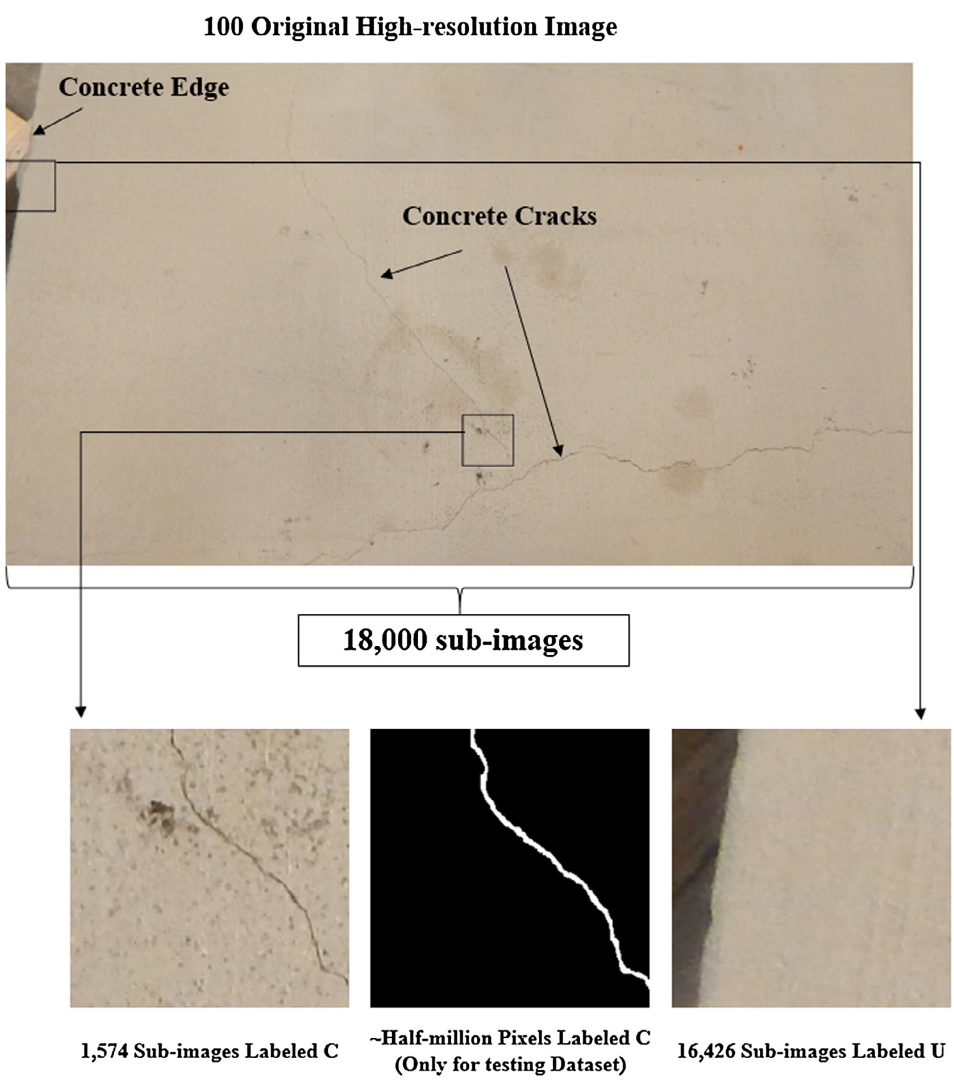

Fig. 1. Illustration of the dataset.