Deep learning aided crack identification and quantification of microcracks of ultra-high-performance fiber reinforced cementitious composite

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Abstract

This research presents an intelligent photo interpretation approach to automatically monitor and characterize dense interconnected microcracks in ultra-high- performance fiber reinforced cementitious composite (UHPFRCC) featuring unique crack patterns in terms of crack number and crack width. The presented approach employs a stereo vision system that integrates binocular and monocular cameras for automatic detection, ranging, and quantification of cracks as well as characterization of crack patterns in real time. This research implemented the presented approach into the evaluation of UHPFRCC in flexural tests and direct tension tests, respectively. Dense microcracks were detected and ranged by the stereo vision system, segmented by an encoder-decoder approach, and quantified by an efficient computer vision approach. Evolution of the cracks was traced throughout the loading process until failure, and a statistical analysis revealed that the crack width was retained while the crack number monotonically increased.

Keywords: computer vision; crack detection; crack quantification; deep learning;

1. Introduction

In current practices, visual inspection via bare eyes is still a widely used approach by many engineers in crack inspection, and a crack meter or scope is often employed to measure the crack opening width after a crack is located. This approach is well accepted historically, but it has limitations: (1) The reliability is limited. The inspection results highly depend on the experience and performance of the inspector. There is lack of effective methods to judge reliability of different projects. (2) Visual inspection is costly and time-consuming. (3) It is difficult to inspect structures in harsh environment and extreme weather, such as extreme temperature and precipitation, while extreme weather is projected to increase in frequency and magnitude due to climate change. This research presents an intelligent interpretation system to achieve real-time monitoring and automatic characterization of cracks in UHPFRCC. Compared with existing approaches used to detect cracks, the proposed system tackles unique cracks in UHPFRCC by utilizing a stereo vision system that integrates binocular and monocular cameras for automatic detection, ranging, and quantification of cracks as well as characterization of crack patterns for UHPFRCC. The presented approach was implemented into automatic evaluation of UHPFRCC plates in direct tension tests. The proposed system can be deployed for automated assessment of cementitious composites with complex crack patterns in material research and engineering structures.

2. Method

Fig. 1 shows the proposed framework for crack detection, quantification, and visualization. The framework includes four main steps: (1) Step 1: Pictures of cracked UHPFRCCs are collected, labelled, and pre-processed to train detection model and segmentation models. The resolution, brightness, and contrast of the pictures are unified in image pre-processing. (2) Step 2: The trained detection model is used to detect and locate crack(s) in a picture of UHPFRCC. (3) Step 3: The area of the picture with crack(s) is analyzed by the trained U-net for segmentation. (4) Step 4: The segmented pictures are used to quantify the number and width of crack(s) using an innovative analysis of the geometry of cracks, which is presented in this research.

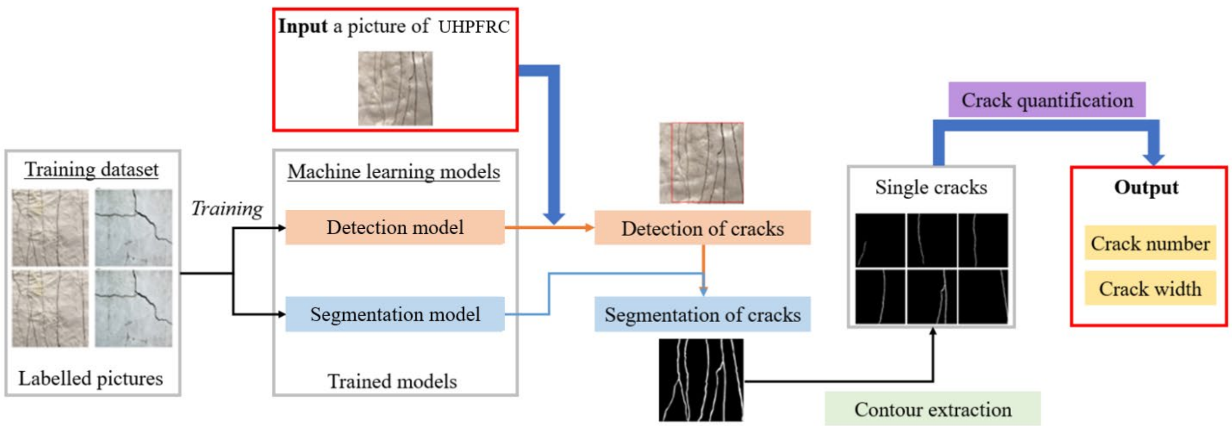

Fig. 1. The framework for crack identification and quantification.

2. Results and discussion

Two different datasets were built to train the deep learning models for crack detection and segmentation, respectively. The dataset for crack detection had 1,500 images, and the dataset for crack segmentation had 1,000 images. All images were resized into 512 × 512 pixels before they were labelled. The images in the two datasets were labelled in different ways. Each of the two datasets were divided into training (80% data) and validation (20% data) sets. YOLO v5 is used to detect the cracks on the images. Once the cracks are detected, the images will be used for segmentation. The image segmentation is completed using encoder-decoder structure. Different networks are selected as the backbone of crack segmentation model. Fig. 13 shows representative segmentation results from the different backbones. ResNet 50 represents the highest segmentation accuracy. The intersection of union (IOU) score and dice coefficient are 0.987 and 0.993, respectively. The distance between the images and camera lens is measure using stereo vision with high fidelity. With the segmented images and measured distance, the cracks can be quantified.

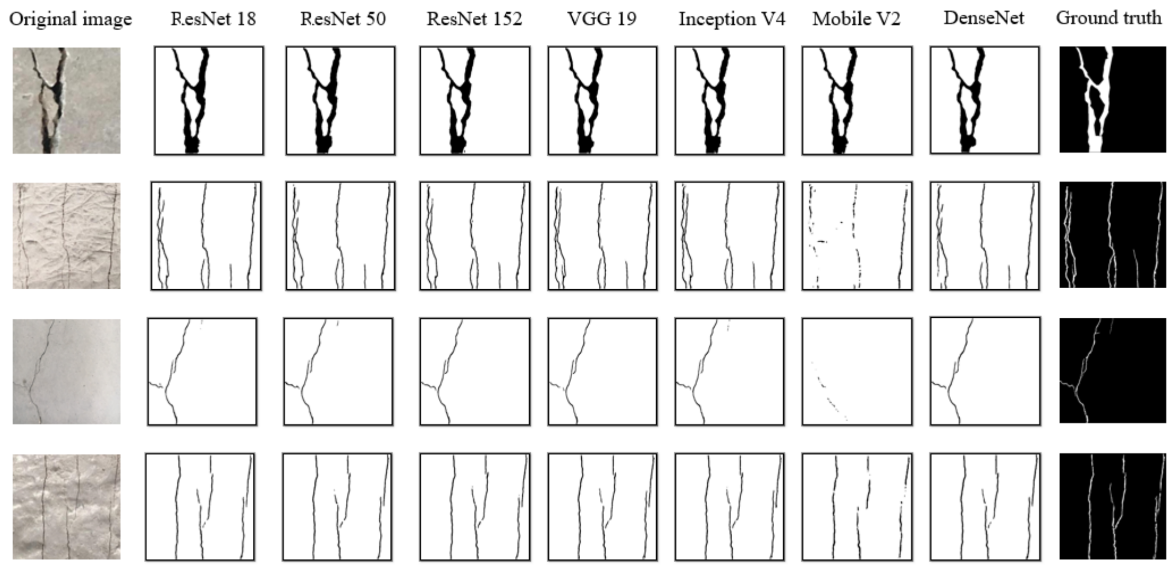

Fig. 2. Representative results of crack segmentation using the different backbone.

In the segmentation image, 10 points at the detected cracks are arbitrarily selected and used to evaluate the crack quantification accuracy. Fig. 16 shows a representative result of crack quantification. The crack width at the 10 points were also measured using the crack scope. The largest absolute discrepancy is generated at point 2, which is 365 µm and 9% of the measurement from the crack scope. The second largest absolute discrepancy is generated at point 3, which is 137 µm and 8% of the measurement from the crack scope.

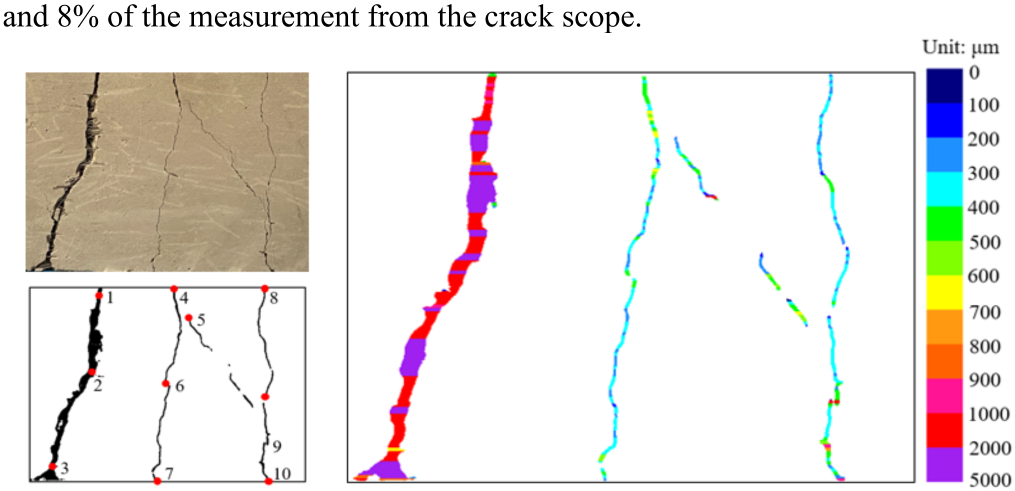

Fig. 3. Visualization of distributed cracks detected and quantified using the presented method.

4. Conclusions

This research proposes an intelligent interpretation approach for automatic assessment and characterization of unique crack patterns in UHPFRCC in real time. The proposed approach integrates stereo vision and deep leaning for automatic detection, ranging, localization, quantification, and visualization of cracks.