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Image Based Inspection and Monitoring of Buildings

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Abstract. The rapid evolution of cameras and drones in the past few years has paved a way for image-based inspection and monitoring of buildings and other structures. This study presents a framework for the development of an automated image-based building inspection and monitoring system. Images acquired from multiple locations of the building can be used to construct a 3D model or a 2D elevation view which is then matched to its BIM (Building Information Modeling) model. The image of each structural member and its dimensions obtained from the matched model is fed to an image processing algorithm which detects cracks in concrete surfaces and measures crack parameters. A machine learning algorithm trained on several synthetic crack scenarios automatically predicts severity of each crack and the corrective action to be taken for maintenance. The detected cracks are color coded and the severity is mapped back to the BIM model so that the current structural state can be effectively visualized. Using several images of real structural members, it is demonstrated that the crack analysis system shows fairly accurate results. Apart from being a smart and convenient tool for structural inspection, the developed framework also results in better operations, planning and facility management.

Keywords: Structural Inspection and Monitoring, Drones, Image Processing, Building Information Modeling, Machine Learning.

1 Introduction

Infrastructures need periodic inspection to ensure that they are performing as intended and do not pose risks to public health and safety. They are liable to deterioration due to environmental factors, overloading, excessive usage or aging [1]. Cracks appear as an earliest sign of deterioration in structures. These cracks may cause material discontinuities and decrease in local stiffness. An early detection of these cracks allows for intervention to be taken to avoid further damage.

Manual visual inspection is the most commonly used crack inspection method in the present scenario. This method however, has poor efficiency as it is time-consuming, uneconomic, may require use of expensive monitoring means for inaccessible regions and might even pose safety risks to the inspectors.

Fortunately, the rapid evolution of cameras and drones in the past few years have paved a way for image-based inspection of tall buildings. For crack monitoring in concrete, drone images combined with digital image processing has shown promising prospect for overcoming the shortcomings of manual visual inspection [2].

This study presents a framework for the development of a fully automated image-based structural inspection and monitoring system. In addition to detecting and measuring cracks in concrete surfaces, the developed system also assigns a severity index to each cracks and suggests corrective action to be taken for the maintenance. Figure 1 provides an overview of the proposed framework.

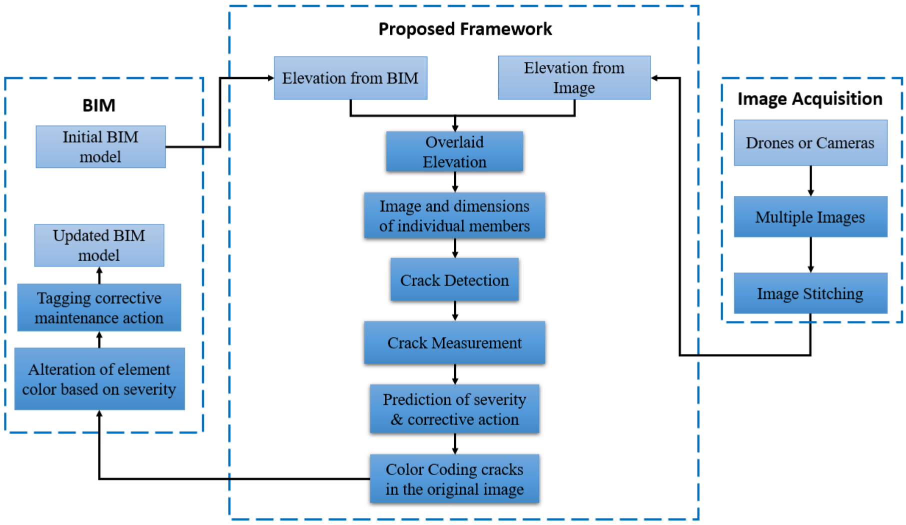

Fig. 1. An overview of the proposed framework

2 System for Image-Based Building Monitoring

2.1 Pre-Processing:

The images can be acquired by flying a drone vertically along the elevation of the building. Images obtained from multiple locations can then be stitched together so that an entire elevation appears as a single image. Furthermore, this elevation can be manually cleaned to remove unwanted materials in the background. An algorithm can also be developed for automatic cleaning. This elevation is then overlaid to its corresponding elvation in the BIM model. The BIM model contains informations such as the unique Element ID for each element along with its coordinate and dimensions. With the help of these coordinates, element level image of each structural member is extracted from the overlaid elevation. This image along with the dimensions and type of structural member is stored for each structural member under its unique element ID.

This information and images will then be read by the crack analysis algorithm. Figure 2 illustrates an example of the process.

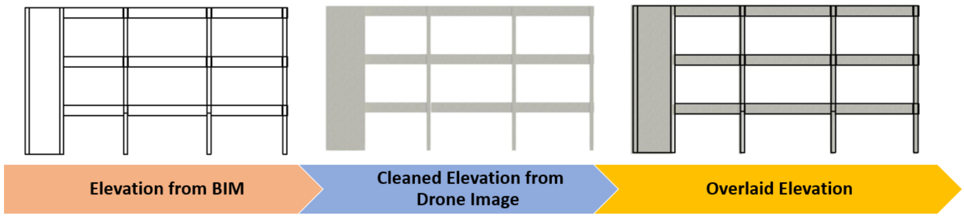

Fig. 2. An example of overlaying elevation from BIM to the elevation from Drone Image

2.2 Crack Analysis:

The crack analysis framework can be divided into three major parts: crack detection, crack measurement and severity analysis. The crack detection module takes the image of each structural member as an input. Using bilateral filtering followed by binary thresholding a potential crack map is created. Utilizing the slenderness of potential cracks compared to potential non-cracks [3], a module is developed that successfully isolates all cracks in the images and creates a binary crack map.

This binary crack map is taken by the crack measurement algorithm which draws rectangular bounding boxes around each crack shape to measure it's length, orientation [4] and co-ordinates of end points. For measurement of crack width, distance transformation is used. Likewise, for determining the generalized position of the crack with respect to the structural member, it is transformed to a generalized local scale.

Severity indexes are usually predicted solely based on crack width and/or density, examples of which can be seen in [5], [6] and [7]. A new severity index was created based on these guidelines and by combining engineering judgement and understanding of concrete mechanics about the effect of crack position and crack type on structural members. Based on the new index, several crack scenarios were created to train the machine learning algorithm. 1080, 1008 and 936 datasets were used for beams, columns and walls respectively with 80% data used for training and 20% data used for testing. Decision tree algorithm was found to give the best accuracy for the datasets. After the decision tree predicts the severity of each crack, a report file is automatically generated that contains the parameters of each individual cracks along with its severity and the corrective action to be taken for the maintenance of that structural element. The framework was built entirely on Python.

2.3 Post-Processing:

For post-processing, the cracks are color coded in the original image of the structural element based on their severity value. A color coding plugin reads the severity level of the element from an external CSV (Comma Separated Value) file by matching the element ID of the BIM element and the CSV file. It then transforms this severity value into its corresponding RGB (Red, Green, Blue) value. A function is created which takes this RGB value and overrides the color of the element so that the final output is the element with its color coded based on its severity. As a result, the current state of the structural member can be easily visualized. Figure 3 shows an example of the initial model and the model automatically color coded based on its severity. Each element is tagged with a report that contains the number of cracks, their measurements, severity and the corrective action to be taken for the maintenance of that element.

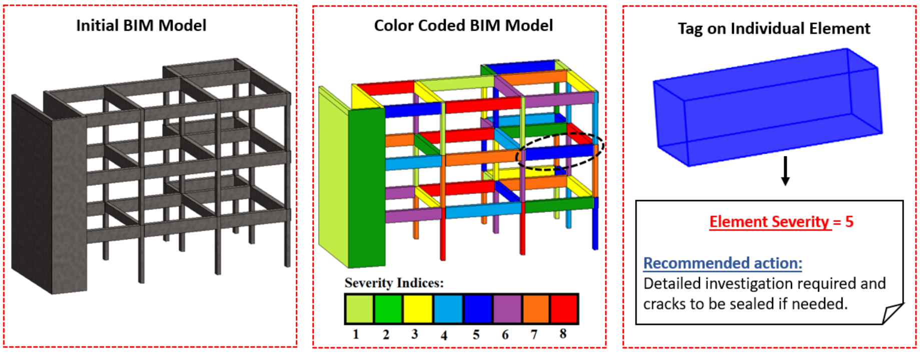

Fig. 3. Initial Model and Color Coded Model with tag on individual elements

3 Monitoring of Some Case Study Structural Members

The presented approach of structural inspection and monitoring is applied to 35 sample images taken around the AIT campus. The images of the structural members were taken and manual measurements of the cracks were carried out on site. The comparison between the actual values measured on site and the values measured automatically by the algorithm was carried out. Figure 4 shows the comparison of these values for a sample beam, column and wall taken for the case study.

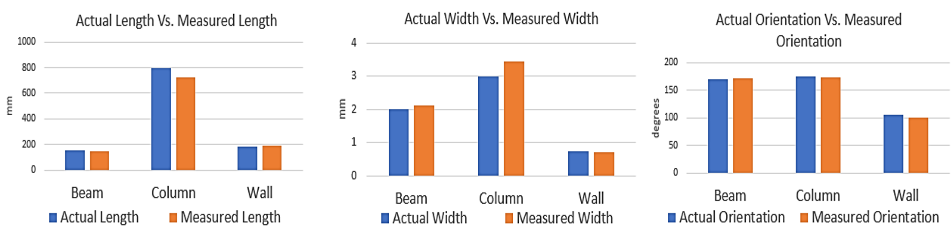

Fig. 4. Comparison of Actual Crack Parameters Vs. Parameters Measured by the System

Based on the 35 samples of structural members, the measurement accuracies for length, width and orientation were found to be 94.16%, 90.57% and 95.92% respectively.

4 Discussion

The developed system functions as a novel method of using image processing and machine learning techniques for inspection and monitoring of structures. It presents a framework for matching elevation from drone image with the elevation from BIM model and then identifying the properties of each structural member. While past studies use image processing for crack detection or measurement, the developed framework goes a step forward and also predicts the severity of the cracks and recommends the corrective action to be taken.

The algorithms used for image-processing are simple, have fast execution speed and are fairly accurate. The algorithm transforms all the structural elements to a local scale so that all the elements are generalized and comparison among them is easier and more logical. For selecting the machine learning algorithm, eight different algorithms were evaluated and it was found that decision tree performs the best as the dataset was based on a set of predefined rules about crack severity.After the decision tree predicts the severity, a report was automatically generated with all information including the severity and the corrective action to be taken based on this severity.

Then the cracks were color coded in the original image as well as back into the BIM model based on their severity. A tag added to each element in the BIM model helps provide additional information about the damage and the corrective action to be taken for the maintenance of that element. The final output helps even a person with limited understanding of structural engineering or the behavioral mechanics of concrete easily visualize the current state of the structure. As each operation in the overall framework is written as a separate module, additional features can be easily upgraded to it. The overall system is expected to act as a state-of-the-art tool for automated building monitoring.

5 Conclusions

This paper presents a framework for the development of a fully automated image-based building inspection and monitoring system. It aims at overcoming the shortcomings of the traditional way of manual visual inspection. The main limitation of the system is that sometimes it may falsely detect marks or other disturbances as cracks. This could be overcomed in the future by identifying and filtering those false detections using deep learning. The developed system is mostly suitable for buildings without glass façade or cladding on its surface. With inclusion of crack scenarios to account for other types of structures, the developed system can be modified to inspect cracks in structures other than buildings. Moreover, the same principle can be applied with slight modification to detect water leakage or for other forensic engineering applications. Using several case study images, it is demonstrated that the measurements done by the developed system is close to the actual field measurements. The system not only acts as a smart and convenient tool for structural inspection but also results in better operations, planning and facility management.

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