AUTOMATED BRIDGE CONDITION ASSESSMENT WITH HYBRID SENSING

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ABSTRACT

It is necessary to assess the physical and functional conditions of highway bridges at regular intervals to ensure they still meet their service requirements. Currently, this condition assessment is mainly performed through visual inspection, which has been identified with several limitations (e.g. the time-consuming assessment process and heavy reliance on inspectors' personal experience). In order to overcome these limitations and enhance the current inspection practice, this paper presents a novel method for automated bridge condition assessment using a hybrid sensing system. Under the method, existing conditions of bridge components are first captured with a stream of point clouds and color images. Then, the bridge components and the defects inflicted on the components are detected utilizing their visual patterns. The detection results are mapped to the point cloud. This way, the 3D information of the components and defects can be retrieved. The bridge condition assessment can be made effectively through the 3D visualization of this information before carrying out any on-site detailed evaluations.

KEYWORDS

Hybrid Sensing, Condition Assessment, Point Clouds, Digital Images, and Bridge Inspection

INTRODUCTION

It is always necessary to inspect the physical and functional conditions of bridges to ensure they still meet the service requirements. The inspection is typically performed every two years or even fewer, considering over 40% of the bridges in Canada have been more than 50 years old (Bisby and Briglio, 2004). During the inspection, bridge conditions are mainly assessed by inspectors through their visual observations of the defects inflicted on the bridge components, such as columns, girders, and decks. The visual observations have been identified with several limitations. For example, the manual observation process is time-consuming, and the observation results are heavily dependent on the inspectors' personal experience and knowledge (FEWA, 1991; FEWA, 1992).

In order to overcome the limitations of manual inspection, several attempts have been proposed to automate the current bridge inspection process. One of such attempts is to automatically retrieve the three dimensionals (3D) as-built/as-is bridge information using remote sensing techniques. The 3D as-built/as-is information records the bridge existing conditions, including the actual details of the defects inflicted on bridge components. Therefore, it could be used to facilitate multiple bridge inspection, assessment and management tasks, including but not limited to post-disaster safety evaluation, renovation/retrofit planning, and maintenance scheduling.

Although the 3D as-built/as-is bridge information is useful, the retrieval of such information is a challenging task (Remondino and El-Hakim, 2006). McRobbie et al. (2010) investigated several off-the-shelf 3D software tools, such as MeshLab, Rhino, TrueSpace, and Phtosynth, and found that existing tools could not fully support the automatic retrieval of 3D as-built/as-is bridge information. A lot of manual editing and correction work is still required, which makes the overall information retrieval process labor-intensive and time-consuming (Zhu, 2012).

This paper presents an automatic method for the retrieval of 3D as-built/as-is bridge information. The method is built upon a novel hybrid sensing system, Kinect, developed by Microsoft®. Under the method, existing conditions of bridge components are first captured by the Kinect with a stream of point clouds and digital color images. Then, the bridge components and the defects inflicted on the components are detected from the images based on their visual patterns. The detection results are further mapped to the point clouds to retrieve the 3D information of the components and their defects. This way, the bridge condition assessment can be made effectively through the visualization of the bridge components and their inflicted defects in 3D. Bridge inspectors could rely on the visualization results to have a better understanding about bridge existing conditions, before any detailed on-site evaluations are carried out. So far, a pilot study has been performed to test the proposed method in the structural lab at Concordia University. The test results from the study have shown the effectiveness and promise of the method for automated bridge conditions assessment.

BACKGROUND

Current Practice of Bridge Conditions Assessment

It is important to maintain the physical and functional requirements of bridges when they are in service. This goal can be achieved by carefully planning and implementing regular bridge repair, maintenance, and rehabilitation activities. Currently, these activities are managed through a Bridge Management System (BMS), where the conditions assessment module is one of the integral parts (Gutkowski & Arenella, 1998). In the condition assessment module, the defects on bridge components are rated on a numerical scale ranging from zero (failed condition) to nine (excellent condition) in the National Bridge Inventory (NBI) (FWHA, 1995) or on a four-state/five-state scale in the PONTIS (Thompson & Shepard, 2000). The rating is given based on the extent and severity of the defects inflicted on the bridge components, which are typically observed by inspectors.

The manual visual observations have a number of limitations that have been identified. For example, the observation results are subjective and not always reliable (Phares et al. 2004). Also, the safety risks are associated with inspectors since they often work at high heights or in heavy traffic zones (NJDOT, 2009). The requirement of experienced inspectors poses a challenge for the construction industry, which is now facing the pressing shortage of experienced and highly trained inspection personnel (TPFP , 2009).

Recent Research Efforts towards Automated Bridge Conditions Assessment

In order to overcome the limitations of manual observations, many attempts have been made to automate the current bridge conditions assessment process. For example, digital image processing techniques, such as edge detection, morphological operations, etc., have been used to automatically locate the defects on bridge components (Abudayyeh et al. 2004). McRobbie et al. (2007) noted that the off-site conditions assessment conducted with digital images could reach a high level of accuracy which was even comparable to the on-site one.

However, the image processing results are typically two dimensional (2D). In order to extend the image processing results, the retrieval of 3D bridge information has been investigated. McRobbie et al. (2010) mentioned that the inspection results based on the 3D bridge information could completely simulate on-site manual observations, and therefore address the limitations of manual observations. So far, the methods for the retrieval of 3D bridge information are broadly classified into two groups. The methods in the first group were built upon the 3D point clouds captured directly by terrestrial laser scanners. The laser scanners could collect millions of 3D points with one scan in minutes, but they are typically heavy and not portable (Foltz, 2000). In addition, the 3D points collected by the laser scanner only record the spatial information of the bridges. As a contrast, the methods in the second group relied on the digital images or videos taken by digital cameras or camcorders. The digital cameras or camcorders are easy to use and portable, but the 3D information has to be estimated indirectly from multiple images or video frames shot under different directions. Both groups of methods have pros and cons in sensing accuracy, resolution, cost, etc. (Zhu and Brilakis, 2010). For this reason, researchers have been investigating the possibility to integrate the point clouds and digital images to enhance the current information retrieval process (El-Omari and Moselhi, 2008; Zhu, 2012).

PROPOSED METHODOLOGY

This paper follows the idea of integrating point clouds and digital color images, and proposes a novel hybrid sensing method for automated bridge conditions assessment. The method relies on the point clouds and digital images captured simultaneously by the Microsoft® Kinect, where the points in the clouds maintain one-on-one relationship with the pixels in the images. Under the method, existing conditions of bridge components are first captured by the Kinect with a stream of point clouds and color images. Then, the bridge components and the defects on the bridge components are detected with digital image processing techniques considering their unique visual patterns. The detection results are further mapped to the point clouds. This way, the 3D bridge conditions can be retrieved and the assessment can be made effectively with the 3D visualization of the bridge components and their defects. Figure 1 illustrates the overall framework of the proposed method.

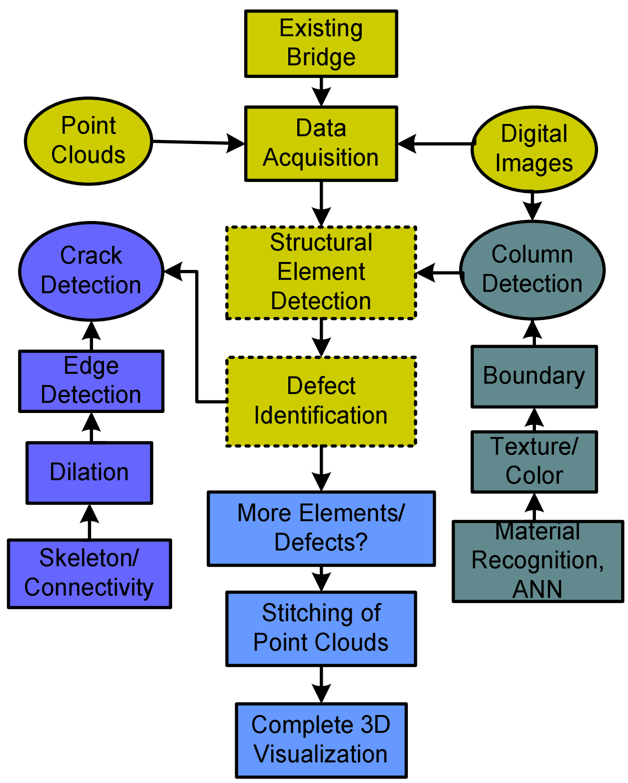

Figure 1 - The Proposed Method

Bridge Components Recognition

The detection of bridge components is the first main step in the proposed method. The detection mainly relies on the visual patterns of the components in color images. Most bridge components, such as columns, beams, and decks, have simple topological and geometrical configurations. Therefore, the focus is placed on the detection of these configurations from the images. Specifically, the contour features of the components are first detected through edge/line detection. Then, the material texture features are extracted with digital filtering. Based on the locations and sizes of the contour and material texture features, the topological and geometrical configurations of bridge components can be retrieved. This way, the bridge components can be automatically detected in the images.

Different types of bridge components can be detected by retrieving their geometrical and topological configurations with appropriate and slight customization. For example, bridge columns (rectangular or circular) in a color image are dominated by long near-vertical lines (contour features) and concrete surfaces (material texture features). Therefore, the columns can be located by searching such cues in the image. More details can be found in the writers' pervious work (Zhu and Brilakis, 2010).

Defects Detection

After the detection of bridge components, the second main step in the proposed method is to detect the defects present on the bridge components. Typically, there could be different types of the defects on the components, such as cracks, spalling, etc. The particular algorithms used for the detection of these defects are chosen on a case-by-case basis depending on the nature of each defect. For example, the cracks in images are composed of a small number of pixels organized linearly. Therefore, in order to detect them, the images are first split into three color planes (Red, Green, and Blue). Then, the appropriate color plane is selected to apply the edge detection algorithms. The edge detection results are morphologically dilated to ensure the connectivity of the cracks and eroded to retrieve the crack skeletons. This way, the cracks can be detected and the crack severity can be measured based on the quantitative information provided by the crack skeletons and their branch points (Adhikari et al. 2012).

3D Mapping

The image-based detection results for bridge components and their defects are limited to 2D. In order to extend the recognition results to 3D, they need to be mapped to the point clouds. Here, the mapping is performed using the one-on-one relationship between the 3D points and 2D image pixels, which is automatically maintained by the Kinect. First, each pixel is checked whether it lies in the areas of the bridge components or the defects in the image. If so, the 2D coordinate of the pixel is retrieved. Based on the 2D coordinate of the pixel plus its depth value, the 3D point corresponding to the pixel can be located and marked in the point cloud. This way, the 2D recognition results for the bridge components and the defects can be extended to 3D.

IMPLEMENTATION AND RESULTS

Implementation

The proposed framework has been divided into different modules and implemented separately. For example, the module for the detection of bridge components was implemented with C++ in the Microsoft Visual Studio. The module for the defection of defects was developed using MATLAB - R2012a. Images and point clouds were transmitted between the modules, so that they can work together. Figure 2 shows the modules in the proposed framework and Figure 3 illustrates that the 3D point clouds and digital images that were captured simultaneously by the Kinect working with a mobile workstation.

Results

The proposed framework was tested for sensing and modeling the conditions of concrete columns in the Structural Engineering Laboratory at Concordia University. Figure 3 shows an example of a concrete column in the lab. The resolution of the images is fixed at 640 x 480 pixels. The image-based detection result for the concrete column has been illustrated in Figure 4, where the detection result is marked red. The detection result was then mapped to the corresponding 3D point cloud (Figure 5), and from that, the concrete column was identified (Figure 6).

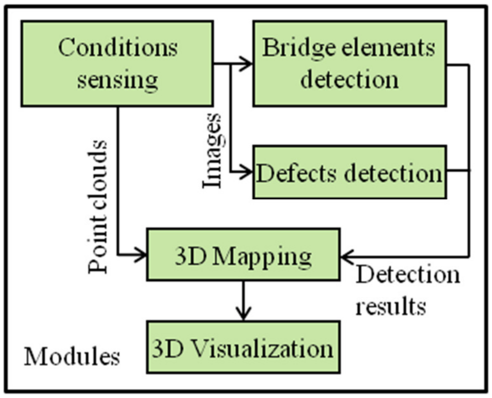

Figure 2 - Modules in the framework

Figure 3 - Kinect working with a laptop

Figure 3 – Image scene of the lab

Figure 4 – Image-based column detection

Figure 5 – 3D point cloud of the scene

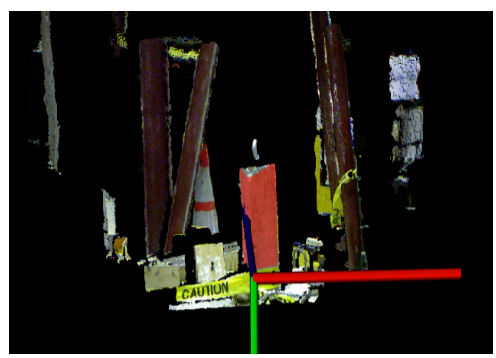

Figure 6 – Column detection in the point cloud

Similarly, the cracks present on the surface of a structural component can also be detected with the proposed framework. Figure 7 shows an example of a crack on the surface of a concrete component. The image-based detection result for the crack has been illustrated in Figure 8, where the detected crack is marked red. The detection result was then mapped to the corresponding 3D point cloud (Figure 9), and from that, the crack was identified (Figure 10).

When the components and defects are identified in the point clouds, their 3D geometrical information can be retrieved. This information represents the existing conditions of the components, which could facilitate inspectors to perform quantitative condition assessments. According to the preliminary results achieved so far, it was found that the proposed method did not have to rely on any pre-created Computer Aided Design (CAD) model for the detection of bridge components and defects. Therefore, the method is expected to be applicable even when inspecting old bridges constructed before the 1960's.

Figure 7 – Image of a concrete surface

Figure 8 – Image-based crack detection

Figure 9 – 3D point cloud of the surface

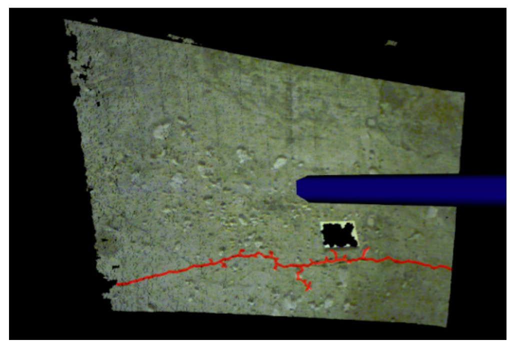

Figure 10 – Crack detection in point cloud

CONCLUSIONS

Routine bridge inspection is always required to ensure that the bridges in-service still meet their physical and functional requirements. Currently, the inspection is performed manually, which has been identified with many limitations, such as the time-consuming process and subjective inspection results. In order to overcome these limitations, several attempts have been proposed to automate the current bridge inspection process. One of such attempts is to automatically retrieve the information of bridge components and their defects using remote sensing techniques. This paper followed this idea and presented a novel method for the retrieval of bridge components and their defects with a hybrid sensing system, Kinect. Under the method, the Kinect was used to capture the existing conditions of bridge components as a stream of point clouds and color images. Then, the bridge components and the defects inflicted on the components are detected from the color images. The image-based detection results are mapped to the corresponding point clouds. This way, the 3D information of the bridge components and their defects can be retrieved, and the bridge condition assessment can be made quantitatively. So far, the method has been tested in the Structures Lab at Concordia University to retrieve the 3D information of concrete columns and cracks. The preliminary results showed the effectiveness of the method.

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