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The Prototype of a Software Application for Laser and Image-based Surface Damage Detection

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Abstract – Nowadays, ageing and natural hazards pose a significant threat to existing structures since these events generally result in substantial structural damage. Assessing the current conditions of these structures enables determining the necessary actions, such as rehabilitation, repair and etc., required for maintaining the operating status of the structures. In recent years, texture-mapped point clouds, which are captured by using terrestrial laser scanners, have been frequently used for assessing the current conditions of existing structures. Author's previous work has been focusing on developing surface damage detection algorithms, which works on the texture-mapped point clouds, for several damage types. This paper utilises the previously developed surface damage detection algorithms in order to generate the new prototype of a software application that is specifically developed for texture-mapped point clouds. The developed software application is capable of importing point clouds, working with images, extracting damage features such as shape and size, determining condition ratings and producing damage reports for future investigations.

***Keywords*:** terrestrial laser scanners, texture-mapped point clouds, point cloud processing, surface damage detection, software application

1. Introduction

Most of the current structural monitoring approaches rely on the measured high accuracy displacements, strains, pressures, or related quantities of a small number of points or the collected information with visual inspection carried out by expert personnel [1]. Thus, the mentioned methodologies utilize discrete samples for determining the current condition of the investigated structures rather than collecting the complete surface data of these structures. Laser scanners, however, provide opportunity to capture the entire surface data, thus it is possible to develop new health monitoring methodologies that do not require mounted sensors on the structure. In the last two decades, researchers have been developing methodologies for using laser scanning technology for both monitoring structures and detecting damage. There are many laser-based damage detection applications in the literature [2-5].

Even though laser scanners are capable of capturing dense data sets that cover the entire surface of structures, it is not easy to detect some damage types including cracks and corrosion directly from raw point clouds, unless the colour information associated with the captured point clouds are available. The additional colour information is then used to extract local properties for enhanced damage localization and quantification. New developments in the laser scanning technology has enabled capturing 3D point clouds with colour information, which can also be referred to as texture-mapped point clouds. Recent research has used laser scanners coupled with cameras for creating photo-realistic models of structures for several purposes [6-8].

The usage of texture-mapped point clouds for damage detection is still not common even though they have been used in several other applications. The author's previous research was focusing on developing methodologies for detecting surface damage from texture-mapped point clouds [9-12]. The two main methodologies previously developed for surface damage detection could be listed as surface normal-based damage detection and graph-based damage detection. The details of these two methodologies are given in Section 2.

This paper focuses on generating the prototype of a software application that utilizes the previously developed surface damage detection algorithms. The algorithms, which are developed during author's previous research, were only available in the form of MatLab codes [13]. Thus, they were not user friendly and any technical personnel, who would want to use these algorithms for detecting and tracking the surface damage information on structures, would require a significant training. In order to expand the usage of the developed algorithms, it is required to put the algorithms in a form that they can be easily understood and manipulated. The developed software application is capable of importing point clouds, working with images, allowing user to pick the appropriate damage type, allowing user to input surface damage detection parameters, extracting damage features such as shape and size, determining condition ratings and producing damage reports for future investigations. The details of the software and a test application are discussed in Section 3 and Section 4.

2. Laser and Image-Based Structural Sensing and Damage Assessment

Two main surface damage detection methodologies were developed in authors' previous research. The first methodology is a surface-normal based damage detection method that only uses the 3D coordinate information for locating rupture, spalling, delaminations. This method is later improved by using intensity values along with the 3D point information for locating small deformations such as cracks, corrosion.

The second methodology, on the other hand, is a graph-based damage detection method that is used for detecting alignment issues and points of discontinuity. This method is an extension of the graph-based object detection method that generates skeletons from cross-section cuts of a voxelized cluster, where a voxel represents a single sample or data point on a regularly spaced, three-dimensional grid, through extracting skeleton of an object in order to detect common structural members. The deviations from the predicted object alignments are used for extracting problematic locations on structures. Then, another method is introduced that converts cross-section voxel representation automatically into a polygon for computing the changes in the cross-section through area calculation and determining the total volume change on the investigated member.

Detected defects are automatically clustered and a mesh grid-based defect area and volume extraction method were developed in order to obtain quantifiable defect outputs for further investigation.

2.1. Surface normal-based Surface Damage Detection

The surface normal-based damage detection method relies on the modal properties of the detected surfaces and/or objects. The relative orientation of the estimated surface normal with respect to a reference normal is used to locate the defected areas on the surface of structures.

The usage of only the normal variations on the surface would be sufficient for detecting large surface defects. However, another parameter should be introduced if certain defects with sizes close to the resolution of the scanner, such as cracks, are to be detected. Thus, the pixel information (intensity) obtained from texture-mapped point clouds is used for enhancing the detection capabilities for smaller defects.

In order to calculate both area and volume of a detected defect, a mesh-grid is fitted to the defect surface. Later, each part of the grid (for the area) and the corresponding rectangular prism (for the volume) are used for quantifying the detected damage. This damage quantification method is used to compute the area and volume associated with each detected defect.

2.2. Graph-based Surface Damage Detection

The second surface damage detection method uses the skeleton of a detected object, which are extracted from the texture-mapped point clouds, for localizing and quantifying local defects. This is an approach for detecting defects, due to local discrepancies through point cloud processing, by using object detection and model comparison.

First, the voxel model of the unorganized point cloud cluster is extracted and this model is used to create a 3D binary image. Second, this 3D binary image is divided into 2D binary images along the length of the cluster (cross-section cuts); subsequently, these images are processed by thinning and/or distance transformation to produce skeleton-graphs and also used to calculate both 2D and 3D shape descriptors.

Defects such as material loss, element discontinuity, or deformed locations are located and quantified by comparing as-is conditions of the structure with the detected object model. Cross-sectional cuts of sections are used to calculate the perimeter, and the area of the cross-section along the length of the member for each point cloud cluster. Then, the results are compared with the model properties at the same location.

3. Details of the Prototype of the Developed Software Application

As mentioned above, this paper discusses the recently developed prototype of a new software application. Even though the texture-mapped point clouds reserve many information related to the structure, it is hard to extract required information from them due to the difficult processing procedures. There have been many studies that focus on how to process point cloud data efficiently so that laser scanners could be frequently used as a part of condition investigation procedure [14-17]. However, currently, it is still hard to use point cloud data for inspection purposes since there are not many software applications for this purpose.

The developed software application is capable of importing texture-mapped point clouds along with images. The imported images are only used for achieving purposes at this point since the imported point cloud already texture-mapped with colour information. First, the users upload the part of the point cloud that they would like to investigate. Once the point cloud is uploaded, it can be seen on the screen. Later, the application gives an option to the user for uploading images related to the damage region. This information is included in the report which is generated once the damage detection is performed. Then, the user is asked to pick the damage type that they would like to investigate. The software automatically asks for the user defined parameters. Once these parameters are entered to the software, the damage detection is performed. The damage detection is completed by using one of the surface damage detection methods described in Section 2, surface normal-based damage detection or graph-based damage detection, depending on the selected damage type. The software shows the condition rating and the related condition rating explanation on the screen. Finally, the software prepares a report for the user. This report includes the images related to the damage, the damage type, the damage features such as area and volume, the condition rating and the condition rating explanation for the detected damage.

The condition rating of an investigated member is determined by comparing the current physical state of the structure to what it was the day it opened. Since we only have the damaged version of the structure once we capture the texture-mapped point clouds, first the initial state of the member is predicted and then the condition rating is determined. Sample condition rating guidelines from different states are adapted in this work to classify the damage severity and to assign labels to the detected damage in a well-known format. As an example, Table 1, which is taken from Manual Bridge Inspection Manual of Ohio, gives the summary of condition rating guidelines for the deck, superstructure and substructure.

Table 1: Summary of condition rating guidelines for deck, superstructure and substructure [18].

1-4 Worst Span	NBIS 9-0 – Deck, Superstructure and Substructure SUMMARY Items **TOTAL BRIDGE**		**Inspector Guidelines**
1	9 - Excellent		
	8 - Very Good	No problems noted	
	7 - Good	Some minor problems	Brief comments as appropriate
2	6 - Satisfactory	Structural elements show some minor deterioration	Comments as appropriate
	5 -Fair	All primary structural elements are sound but have minor section loss, deterioration, spalling or scour	Document deficiencies quantitatively with descriptive comments.
3	4 - Poor	Advanced section loss, deterioration, spalling or scour	Candidate to establish monitoring parameters with specific locations to track the deficiencies rate-of-change at the next inspection. In addition to quantitative documentation take photos, make sketches and/or establish monitoring control points.
	3 - Serious	Loss of section, deterioration, spalling or scour has seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present	Document deficiencies quantitatively with descriptive comments; establish monitoring benchmarks. Discuss with Program Manager, structure may be prone to localized failures.
4	2 - Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken	Document deficiencies quantitatively with descriptive comments; establish monitoring benchmarks. Contact Program Manager; candidate to dispatch repairs and or road closure. Confirm in writing.
	1 - Imminent Failure	Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put bridge back into light service	Dispatch personnel for immediate closure. Notify Program Manager. Confirm in writing.
	0 - Failed	Out of service - beyond corrective action	

4. Results and Discussion

The prototype was tested on a texture-mapped point cloud sample extracted from The Bowker Overpass data. This bridge is located in Boston, Massachusetts and it is a steel girder bridge with a composite deck carrying Charlesgate Street over Commonwealth Avenue, Beacon Street, and Interstate 90 [19]. The screenshot of the prototype for the mentioned test is given in Figure 1.

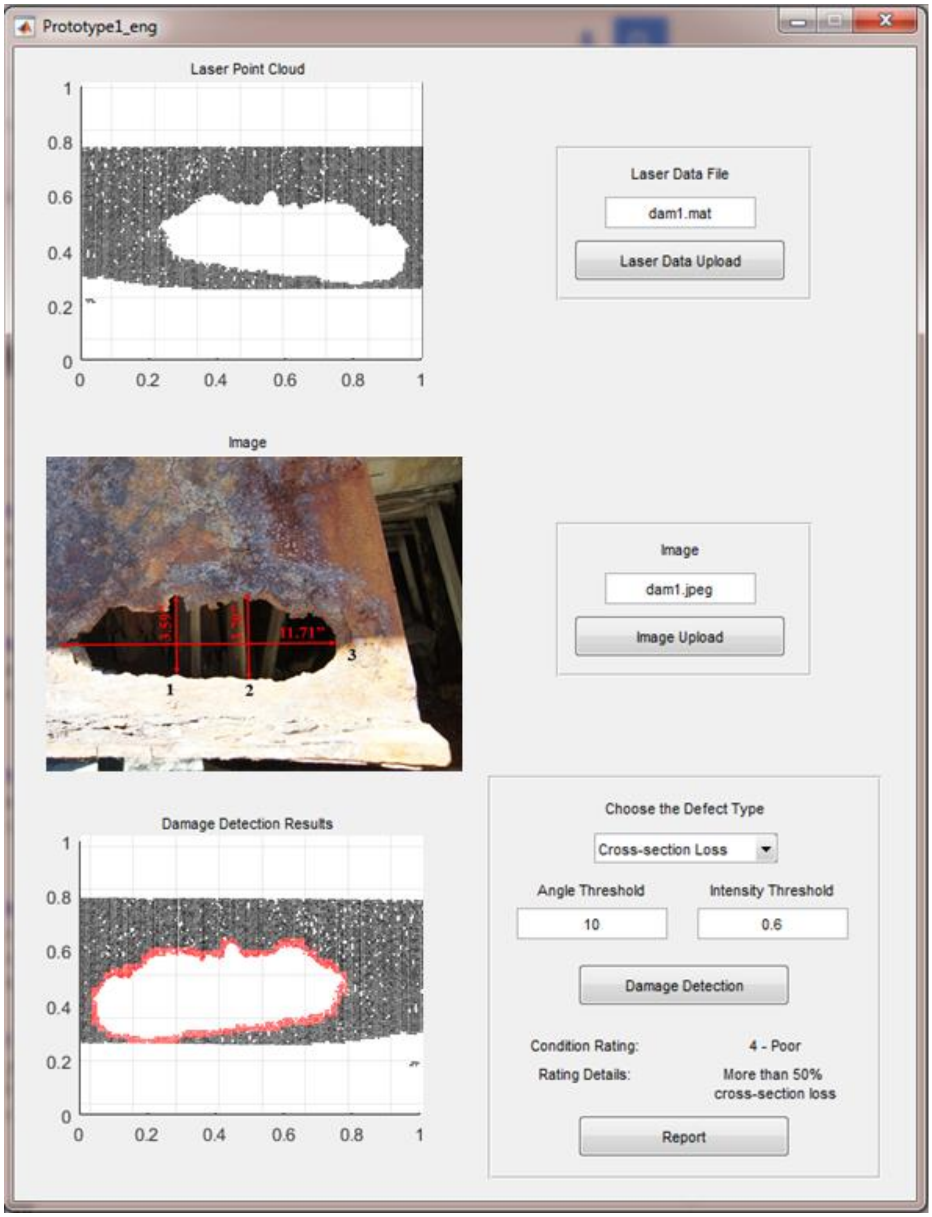

Fig. 1: The screenshot from the testing of the prototype with Bowker Overpass sample data.

First, the dam1.mat file is uploaded and the texture-mapped point cloud for the extracted region is visualized. Later, dam1.jpeg file, which is the image of the extracted region, is uploaded to the prototype. The following step is to select the damage type, which in this case is cross-section loss. The software automatically asks for required parameters for the selected damage type. This type of damage is suitable for been detected by using surface normal-based surface damage detection method. Thus, the two parameter related to this method is asked. For this application, angle threshold is selected as 10 degrees and the intensity threshold is taken as 0.6. The details for the parameter selection is discussed in author's previous research [9]. Once the damage is detected, it is visualized as damage detection results and the condition rating is determined. When the user hits the "Damage Detection" button, the dimensions of the defect is also computed even though they are no reflected on the screen. The results for the damage dimension detection is given in Table 2. Table 2 also included the hand measurements taken from the damage location and the error associated with the automated damage dimension computation.

Table 2: Comparison between the field measurements and computed section loss dimensions for S1.

Measurement Number	Field Measurement (cm)	Computed Dimension (cm)	Error (%)
1	9.12	9.02	1.11
2	9.40	9.24	1.62
3	29.74	29.87	-0.43

Finally, the report of the damage detection process is automatically produced by the software. This report consists of the image, the damage results, the damage features such as dimensions, condition rating and the condition rating explanation for the investigated region.

5. Conclusion

In this paper, the details of a new software prototype, which is specifically developed for surface damage detection, are discussed. First, some information on laser and image-based structural sensing and damage detection is given. Then, the two main surface damage detection methodologies developed in author's previous studies, surface normal-based damage detection and graph-based damage detection, are explained. Later, the information on this recently developed software prototype for surface damage detection software is laid out. Finally, the results of the testing performed by using an extracted dataset from Bowker Overpass laser point cloud, are discussed.

Even though the created software application is not fully developed yet, it is capable of performing damage detection for several damage types and recording the extracted information. The future research will focus on advancing the software in order to extend the damage detection capabilities as well as the visualization and the reporting features.

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