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A SEMI-AUTOMATIC MEMBER DETECTION FOR METAL BRIDGES

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Abstract:

Terrestrial laser scanners (TLSs) are prominent non-contact instruments for acquiring highly detailed geometries of bridge components in only minutes. A TLS can be a strategic instrument for data collection for bridge inspection and documentation, because it can reduce significantly required field time and auxiliary equipment. To deploy a TLS in this field, a semi-automatic method for post-processing a point cloud for documentation of a historic metal bridge is proposed. In this work, generating 3D model of existing structural members and identifying connection characteristics are mainly of interest. The Guinness Bridge built in 1880s in Dublin, Ireland is presented as a case study for the proposed semi-automatic workflow.

Keywords: Terrestrial Laser Scanning, Point Cloud, Connection, Historic Metal Bridge, Damage, Documentation

1. Introduction

Many century old metal bridges remain as part of the transportation networks. This can be problematic as their performance may negatively be impacted by uncertainties in load capacity and excessive losses in cross-section due to corrosion. To provide sufficient information for a decision on rehabilitation or replacement or preservation, the problems of functional deficiencies, damage and structural deficiencies must be addressed. However, obtaining the relevant information is complex and time consuming by using traditional methods [1]. Terrestrial laser scanners (TLSs) offer a non-contact method for acquiring surface information of the structural members quickly and accurately. Subsequently, the primary structural dimensions or damaged surface can be extracted from the TLS data. This paper proposes a method for post-processing TLS data to identify 3D structural member model and connection parameters (e.g. number and type of rivets).

2. Background

Since a systematic overview of the application of TLSs in bridge engineering has published elsewhere [2, 3], this background section is restricted to laser based method for section and connection identification. In an investigation of laser scanning application on transportation projects, Jaselskis et al. [4] noted that while two-dimensional (2D) and three-dimensional (3D) geometric structural components like lines and circles can be manually drawn from a TLS point cloud, edges of objects are hard to identify. In that pipeline, a portion of the steel Charnplain Bridge was manually generated in 3D using commercial modelling tools [5]. Similarly, Walsh et al. [6] used a region growing with a smoothest constrained to extract the point cloud belonging to individual segments of a concrete pile cap and then fitted a surface by using a least squares approach. They reported that the reconstructed geometry was within allowable tolerances. Cabaleiro et al. [7] used a Hough transform to extract flange and web lines of steel frame connection components from 2.5 dimensional density images, and completed the model using Solidworks 2012 software. In preliminary work to identify steel cross-sections, Yeung et al. [8] projected the point cloud of the cross-section onto a 2D plane, and then the binary images were created the point cloud. There an evolutionary algorithm was used to find the best match between the binary image and a standard steel section. Cross section errors varied between a 15% overestimation and a 41% underestimation. Yeung et al. [8] also used a Hough transform to detect connection holes resulting in an average error of the hole's radius of 6.3mm.

3. Methodology

This research study is to propose a method for post-processing TLS data for the documentation metal, truss bridges but can be extended for other steel structures. The algorithm involves: (1) 3D metal structural member and (2) connection identification. The 3D model of the metal structures can be generated from cross-sections along the structure's longitudinal direction. The rough cross-section dimension was determined from its point cloud, and the real section is the section from best matches an industry standard shape selected from a database. In contrast, the connection identification procedure provides the number of rivets and a type based on the rivet head diameter.

The structure used for validation was the Guinness Bridge, also known as the Farmleigh Bridge, a Victorian metal bridge over the river Liffey built in 1880 [9]. This 4m wide and 4m high metal lattice truss bridge had a 52m clear span. No longer existing, the decking was a series of concrete arches spanning between the floor beams. The bridge was scanned with a TLS Leica ScanStation P20 (technical specifications available in Truong-Hong et al. [10]). The overall bridge was scanned with a sampling step of 6.3mm@10m and then at 1.6mm@10m for the connection details. Notably, the bridge was accessible from only one side.

Fig. 1. A point cloud of Guinness Bridge

After collecting data, point clouds from different scans were registered together, and irrelevant points (e.g. from the terrain) were removed manually within the scanner's proprietary software. Subsequently, the point cloud was exported as ASCII format with x, y, and z coordinates for each data point.

4. Implementation

4.1 Generate 3D metal structure

As manual generation of a 3D model is time consuming, the proposed algorithm is aimed to automatically identify the cross-section for 3D structure model reconstruction from TLS data. The workflow is shown in the Fig. 2.

Fig. 2. Workflow of cross-section identification

After extracting a point cloud of a structure of interest by using proprietary software of the scanner (step 1.1), a longitudinal axis of the structure was aligned to the z-axis [data points of the cross-section are now on the x-y plane (step 2.1)]. For this task, a region growing method [11] was employed to extract the point cloud of the flange and web planes. The result of the segmentation of lateral beam No. 4 is shown in Fig. 3a. The eigenvectors of the predefined segment [12] were used to align the structure. To generate a 3D member model, the cross-section along the longitudinal axis needed to be defined. The data points of each cross-section were extracted based on a predefined position of the section and interval thickness (Step 2.2). Additionally, kernel density estimation was employed to detect primary sides (web and flanges) of the cross-section, where the bandwidth of 5mm was empirically chosen. As shown in Fig. 3b, a probability density shapes were generated from x and y coordinates of the cross-section and distinguished peaks are that the peaks have values significantly larger than others are showed the web and flange side. Based on the number of distinguished peaks and relationship of intersection between the distinguished peaks in vertical and horizontal directions, the type of standard cross-section can be determined. For example, with I section, there are three peaks: one peak for the web and two peaks for the flanges and a vertical peak intersects to the horizontal peak around its middle, while with L section there are only two peaks: one peak for the web and one for the flange and a vertical peak intersects to the horizontal peak around its edge. Next, the primary dimensions (height, H and width, B) were established as the peak lengths. Next, the algorithm determined the best matching standard cross-section from a

database, which has a minimum root mean square error between the estimated dimension and standard ones (step 2.3).

Finally, a new scanning method was developed to map the matching standard cross-section onto the point cloud of the section, where the web and flange sides were mapped onto the vertical and horizontal peaks, respectively, and the distance between the data points to the mapping cross-section was minimized (step 3.1) (Fig. 3c). After mapping standard cross-sections, the results were exported to a DXF format, compatible for 3D member model generation within a CAD program (steps 3.2 and 3.3) (see Fig. 3d).

Fig. 3. Generating a 3D model of the bottom lateral beam No. 4

4.2 Connection

The proposed work shown in Fig. 4 determines the number and type of rivets. The idea was that the number of rivets equals the number of holes due to the occlusion of a rivet's head and that the rivet type can be determined based on the diameter of a rivet head. The algorithm was applied to the connection between the top chord and the diagonals but can be used elsewhere.

Data points of a region containing the connection were separated from the rest of the bridge data (step 1.1) (Fig. 5a). The region growing method was employed to extract the data points of the connection plate (step 1.2) (Fig. 5b). Next, an outlier remove procedure (step 2.1) was proposed to iteratively eliminate outlier points – those having a distance from the point to the fitting surface of the connection plate that is larger than the perpendicular noise level of the range measurement [13, 14]. The process was considered complete when no outlier point remained or the deviation between the normal vectors of two consecutive fitting planes was less than 1 degree. Then, the remaining points were projected onto the fitting surface (step 2.2) (Fig. 5c).

A combination of an angle criterion and 2D cell grid was proposed to determine the data points on the boundaries of the (step 3.1). A 2D cell grid with a cell size of 3 times of the average sampling step was generated to represent the data points. The cell was classified as “full”, if it contained at least one data point; otherwise it was classified as “empty”. The holes caused by the rivet head occlusions are considered as empty cell groups within the data set (Fig. 5d). From the empty cell group, the candidate points for boundary points were data points within the full cell around each hole [15]. The candidate point is considered a boundary point, if the maximum angle between two consecutive k nearest neighbour (k NN) points is larger than the angle threshold of 90 degrees [15] (Fig. 5f). Finally, the least squares method was employed to fit the hole based on its boundary points (step 3.2) (Fig. 5g). Results show that all rivets were detected, and the average diameter of the holes was 36.23mm with a standard deviation of 0.52mm.

Fig. 4. Workflow to determine connection

Note: ^(*) blue points corresponding to a segment number 2 are the data points of the connection plate of interest;
^(**) colour cells are the holes after removing data points of rivet heads

Fig. 5. Procedure to detect rivets and the diameter of the rivet heads

5. Discussion

As TLS can save up to 90% of the time required data acquisition, it has been widely used in civil engineering. The proposed method automatically identified the cross-section of metal structural members of a historic bridge and subsequently generated 3D models from the structural members. The 3D model is appropriate for finite element analysis to assess bridge capacity or for general documentation. The proposed method can be used to identify the cross-section from different standards, presuming the member dimensions are entered into the database.

Although the proposed method was successful in generating 3D structural member model, there are still many challenges affecting the quality of the final model. Scanned data points of structural members can be incomplete due to occlusions. Furthermore, noise in the scanned data caused by mixed pixels can affect on extracting data points of the cross-section edges, particularly ones of the flange edges. Finally, noise in the data generates errors in overall dimensions of the cross-section, which cause incorrect determination of the standard section, because the difference between two consecutive sections in the standard is small. These issues were also raised by Anil et al. [16].

A combination of an angle criterion and 2D cell grid worked properly in identifying characteristics of the connection. While the method is appropriate for the flat plane connections, it may fail to detect they type and number of rivets when the connection is scanned with a sampling step that is equal to or greater than half of the rivet head diameter. Furthermore, noise in the connection data and configuration of the rivet head can restrict hole determination in the connection plate. When the noise is larger or the thickness of the rivet head is small, the data points of the rivet head may not be removed completely. This would cause incorrect determination of the type and number of rivets.

6. Conclusions

There is rarely original documentation of historic metal bridges that remain part of the transportation network of many communities. As this complicates structural assessment, TLS is useful in acquiring surface information for such external geometries. This paper proposes a set of techniques appropriate for automatic sizing detection of structural members and affiliated rivets. The approach also enables the automatic conversion of the remote sensing data into a format appropriate for computational analysis. The proposed algorithms were successful in reconstructing standard cross-section of the Guinness Bridge built in 1880s in Dublin, Ireland. Furthermore, the algorithm can be extended to generate modern standard, metal cross-sections from various standards. However, efforts must be made to minimize noise in the data to prevent improper section identification.

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