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Toward automatic generation of 3D steel structures for building information modelling

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ABSTRACT

Building information models (BIMs) are becoming standard for new construction. Extending this trend to existing structures is complicated because of an absence of reliable documentation and the cost of generating it anew. To overcome this problem, this paper proposes a method to identify automatically structural steel members from a terrestrial laser scan point cloud and to generate that geometry in a BIM compatible format. The proper shape and dimensions of the cross-section are established by employing kernel density estimation. A method associated with measured metrics is introduced to determine the best match of various cross-sections, from a prepopulated library. The proposed method successfully identified up to 92.0% of the required cross-sections and 81.3% of structural members across two steel frames of different shapes, sizes, and configurations.

1. Introduction

Globally, building information modelling (BIM) adoption is growing 70% annually amongst architect, engineer, contractors, and facility managers [1]. The technology allows all stakeholders to share, exchange, and manage information about a building's components throughout a building's entire lifecycle [2]. At its core, BIM requires a three-dimensional (3D) digital representation of the current facility, but existing standards and methods to populate BIM software were developed primarily for brand new structures. This is problematic, if that input is not readily available. Furthermore, during a facility's lifespan conditions may change, thereby causing significant changes from the initial design and construction. As-built BIMs can be instrumental in tracking such changes but input mechanisms are needed to facilitate this accurately and economically. To this end, several researchers have worked on generating as-built BIMs from various digital data sources (e.g. image and laser scanning data) [3,4]. Terrestrial laser scanning (TLS) is rapidly emerging as one of the most efficient means to capture detailed surface objects quickly and accurately, with sub-millimetre accuracy, TLS data are increasingly used to create 3D models for as-built models compatible for BIM [5–11]. This paper presents a new, fully automated approach to reconstruct structural steel members from point clouds for BIM usage. The proposed method overcomes current drawbacks related to the required time and resources needed to reconstruct 3D models of existing metal structures [12,13]. Such structures are extremely common; for example, steel used in construction and infrastructure represents more than 50% of overall 1606 million tons steel produced in 2013 [14].

2. Related works

Since a systematic overview of BIM and automatic, as-built modelling has been published elsewhere [15–18], this background section is restricted to structural member reconstruction from laser scanning point clouds. Detailed research on laser scanning for the geometric reconstruction of concrete structures is first presented followed by a similar review for structural steel.

Feature extraction from TLS for concrete structures has been applied to a fairly wide range of applications using a variety of techniques. For example, Walsh et al. [19] used a region-growing technique with a smoothness constraint to extract the subsection of a point cloud belonging to individual segments of a concrete pile cap, and then used a least-squares approach to fit the surface to the extracted points. They reported that the reconstructed geometry was within allowable tolerances, but no values were quoted. For determining quality assessment of precast concrete panels, Kim et al. [8] used a vector sum algorithm to extract edges and corners to estimate dimensions from TLS data. Similarly, Mosalam et al. [20] set up a laboratory test to measure dimensions and locations of concrete duckband specimens to check construction errors, where the exterior dimensions were manually measured from a cross-section of a point cloud.

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The discontinuous nature of the dataset continues to be a major challenge during post-processing For example, in an investigation of laser scanning applications for transportation projects (including a section of highway, concrete pavement, and a bridge structure), Jaselskis et al. [21] noted difficulty in identifying object edges during the manual drawing of 2D and 3D geometric structural components (i.e. line and circle) from a TLS point cloud. When similar efforts using a commercial computer-aided design (CAD) package based on best-fit techniques were applied to a portion of a complex, steel Champlain Bridge [22], manual intervention was needed as a critical part of the pipeline to create a complete model. In an effort to develop a steel bridge model for damage assessment via a finite element approach, Stull and Earls [24] created a parasolid model of bridge structures from a TLS point cloud using the software Geomagic, where the model's surfaces consisted of triangular polygons. The proposed procedure was applied to a skew bridge consisting of a three-span, continuous steel I-girder. Although the Geomagic software can generate meshes of structural steel members from a point cloud for finite element analysis to determine damage level of the girders, the automatic generation of a 3D solid model with detailed information (e.g. a type of section, height, width, web and flange thickness) has yet to be reported.

To understand the influence of data acquisition and the challenge of closely sized generic steel sections when identifying steel sections, Anil et al. [23] investigated four manual methods: (1) point-to-point, (2) distance between edges, (3) distance between plane-plane intersection lines, and (4) cross-section tracing. When compared to standard AISC sections, the best method only achieved 18.75% accuracy for columns and 39.68% for beams. The investigation identified occlusions, mixed pixels at member edges, and noisy data as major impediments. Thus, automatic identification of steel structural member from laser scanning data is still a major challenge.

In attempting to developing automatic algorithms to identify the steel section, Cabaleiro et al. [12] used a Hough transform to extract automatically flange and web lines of steel frame connection components from 2.5 dimensional density images and completed the model using Solidworks 2012 software. However, the web and flange thicknesses could not be identified. Yeung et al. [13] applied an evolutionary algorithm to filter the best-matched, standard section from a predefined library using the number of matching pixels between the standard section and the binary image as the threshold. In that approach, cross-section errors varied significantly (−41% to +15%). Notably, they also employed a Hough transform to detect bolt holes, which resulted in an average hole radius error of 6.3 mm.

In practice, various standalone commercial products and CAD plug-ins have claimed to assist in defining locations and cross-section [e.g. Trimble RealWork (Trimlbe Navigation Limited) and Edgewise Structure Modelling Tools (ClearEdge 3D)]. In general, these packages rely heavily on manual intervention and user experience for section selection and alignment. Therefore, an algorithm is needed to automatically determine a section's shape, size, and align, which are the aims of the proposed algorithm.

3. Proposed method

The goal of the proposed method is to automatically identify from TLS point cloud data cross-sections of standard steel structural components for reconstructing 3D models compatible with BIM. The proposed method involves 3 main steps (Fig. 1). In Step 1, a point cloud (with *x*-, *y*-, and *z*-coordinates) of each gridded structure member is manually separated from the point cloud of whole structure by using proprietary software of the scanner. Notably, the data points affiliated with the connection are not included. Step 2 estimates a shape and rough dimensions of the cross-section based on the distribution of the point cloud in the vertical and horizontal directions. This information is then compared to standard sections stored in a database to select a set of closely matched sections. To determine the best match section, Step 3 introduces a scanning method to map the selected standard sections onto the point cloud cross-section. The best-matched section is determined based on an overall score obtained from the overlap extent between the selected standard sections and the point cloud. Next, a 3D model of each structural member is generated by extruding along the alignment of the cross-sections. The 3D model can be derived by assembling the 3D sub-models of all individual members. Following sections present details of Steps 2 and 3.

3.1. Determine shape and rough dimensions of a cross-section (Step 2)

In a 3D sense, since a structural member is at an arbitrary orientation, the point cloud of the member must be aligned to provide a means for extracting the relevant portion of the point cloud. In this step, a region growing-based octree is employed to segment the point cloud belonging to primary planes (flange and web) separately

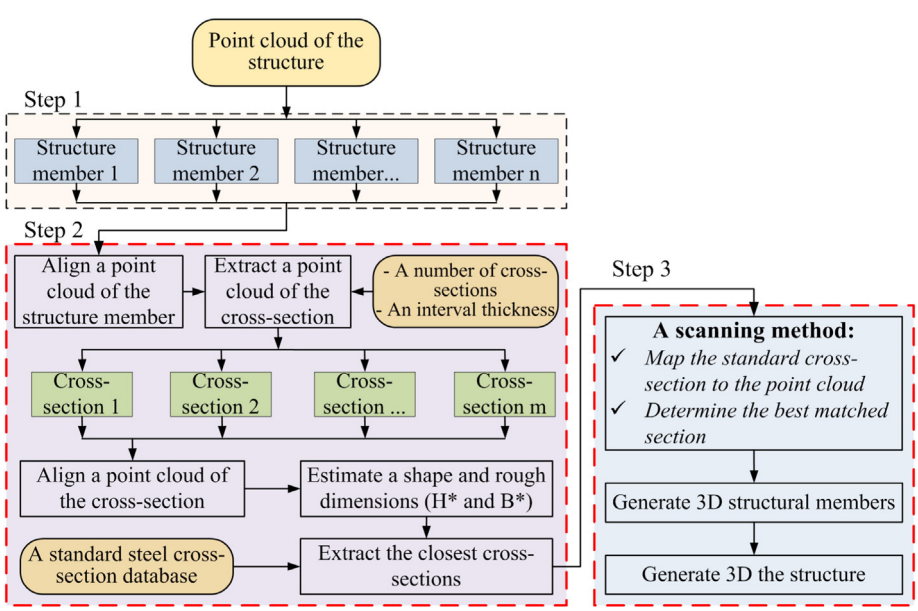

Fig. 1. Workflow of the proposed method for 3D structure model generation.