Automation in Construction 71 (2016) 346–358

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Pipe spool recognition in cluttered point clouds using a curvature-based shape descriptor

Thomas Czerniawski *, Mohammad Nahangi, Carl Haas, Scott Walbridge

Department of Civil and Environmental Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada

ARTICLE INFO

Article history:
Received 21 October 2015
Received in revised form 28 June 2016
Accepted 13 August 2016
Available online 25 August 2016

Keywords:
Building information models
3D reconstruction
Object recognition
Point clouds
Curvature
Bag-of-features
Pipe spool

ABSTRACT

Automating dimensional compliance control and progress tracking using computer vision has been identified as a central opportunity for improvement in the construction industry. Current 3D imaging sensors provide massive amounts of spatial data that remain underutilized due to the prohibitively time-consuming manual process of extracting usable information. Desired information is typically centered on a specific object of interest within 3D images, so there is a need for construction specific object recognition processes. In this paper, we present an automated method for locating and extracting pipe spools in cluttered point cloud scans. The method is based on local data level curvature estimation, clustering, and bag-of-features matching. Experimental results from two point clouds containing pipe spool objects demonstrate the method's ability to successfully extract spools from cluttered scenes as well as differentiate between similar spools in a single scene.

1. Introduction

Among the many challenges of construction management are the awareness and control of 3D geometries. Progress tracking, dimensional compliance control, and the location, movement, and assembly of materials are all critical processes that rely on 3D spatial data. Utilizing new sensor networks and communication technologies to improve the efficiency of the processes by which people, processes, materials, and information interface is one of the central opportunities for breakthrough improvement in construction [1,2]. Integrating and automating the information flow regarding 3D geometries on dynamic and cluttered construction sites will require advanced capabilities in site metrology and 3D imaging, construction object detection and localization, data exchange, and design data to as-built comparison. These capabilities will be the foundation for the next generation of assessment tools that empower project leaders, planners, and workers.

3D imaging systems are a class of these sensor technologies growing in popularity. 3D imaging in the construction industry is often referred to as laser scanning and it has been profoundly affecting project surveying since the 1990s [3]. 3D imaging sensors enable the capture of existing structural and terrestrial conditions objectively, accurately, quickly, and with greater detail and continuity than any manual methods. Current applications of laser scanners by construction firms include schedule and progress tracking [4], creating complex as-built construction documents and 3D models [5], path planning, crane setup and clearance evaluation, quality assurance, retrofitting, controlling deformations, floor grading, steel column verticality, and base plate and tie point locations [3,6,7].

Despite 3D imaging's ability to provide massive amounts of spatial data, its potential is limited because extracting usable information from the collected data remains primarily a manual process. Manually extracting information from the raw 3D images and running analysis is painstaking, requires many man-hours and specialized personnel training, and is therefore not well suited for real-time or rapid decision making on a large scale. Automating this process is the fundamental enabler for further developments in automated spatial analysis and information flow. Search and extraction involves many technical challenges that stem from the variability of spatial data and other operational realities such as non-uniform point density, clutter which may be in contact with the object of interest or of similar shape and size to the object of interest (Fig. 1), occlusion, missing/erroneous data, as well as sensor noise and inaccuracy.

In this paper, a method is presented for locating and extracting pipe spools in cluttered point clouds. A 3D CAD design file is specified as the search query and is abstracted using a local curvature characterization algorithm that avoids costly preprocessing of the raw point set data. The curvature characterization algorithm is then used to filter the points in the cluttered 3D point cloud based on the similarity of their curvatures to the curvatures in the search query. The points accepted through the filter form a hypothesis space. The hypothesis space is clustered into

* Corresponding author.
E-mail addresses: tczernia@uwaterloo.ca (T. Czerniawski), mnahangi@uwaterloo.ca (M. Nahangi), chaas@uwaterloo.ca (C. Haas), swalbridge@uwaterloo.ca (S. Walbridge).

http://dx.doi.org/10.1016/j.autcon.2016.08.011
0926-5805/

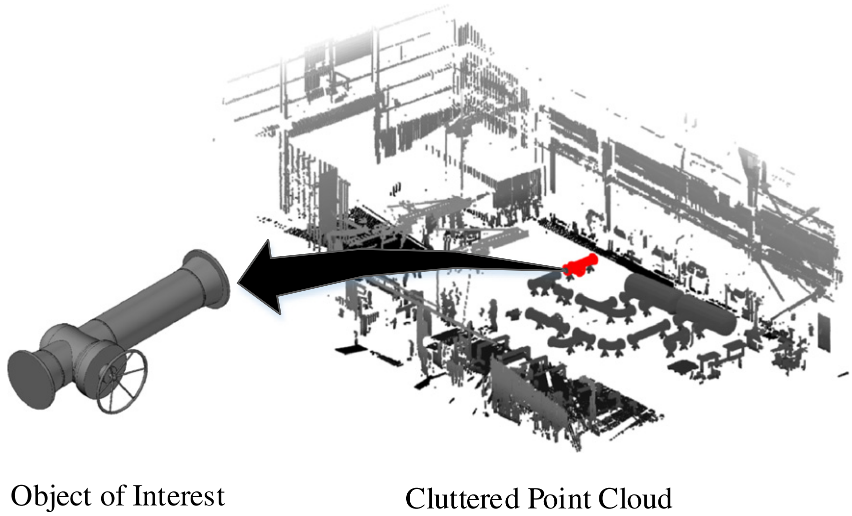

Fig. 1. Extracting points associated with structural frame module from cluttered 3D image of industrial fabrication facility.

discrete hypothesis objects using density based clustering, DBSCAN [8]. Curvature frequency comparison using Bag of Features (Section 2.2.2) refines the hypothesis pool and the best hypothesis is presented as the extracted object of interest. The underlying assumption of the method is that pipe spools of interest must have a distinct curvature patterns to that of the surrounding clutter. The search and extraction methodology is presented in Section 3 with the curvature characterization algorithm presented in Section 3.3.1. Sensitivity analysis and method validation on two test datasets are presented in Section 4.

The contribution of the paper is the presentation of an object recognition methodology for extracting pipe spools from cluttered point clouds using local data level curvature estimation, clustering, and bag-of-features matching. The motivation for the work is presented in Section 2.1 and related background literature on industrial object recognition is reviewed Section 2.2.

2. Background

2.1. Automated visual inspection in construction

There has been relatively little work on construction specific object recognition from laser-based 3D imaging systems. The primary application areas for construction are automated dimensional compliance control, progress tracking, and equipment guidance. In particular, many methods for visual inspection outlined in the literature fall short of full automation because of the absence of a reliable object recognition method. Only by fully automating these systems will they become unobtrusive enough for fabricators to adopt them. Once adopted, they will continuously collect data that can be mined for operational insights that will improve fabrication efficiency and mitigate rework. In the construction literature, rework is the wasteful effort involved in redoing work that has not yet yielded a product adequately conforming to contractual requirements [9,10]. Rework directly and significantly contributes to cost and schedule overruns on construction projects [11,12]. The function of QA/QC personnel is to perform lifecycle inspections to mitigate these rework situations. Inspection is the process of determining if a product deviates from a given set of tolerance specifications. The predominant processes for monitoring the critical dimensions of an assembly involve a temporary production stoppage and manual direct contact measurement devices such as measuring tapes, calipers, custom gauges, squares, and straightedges. These processes can help fabricators evaluate whether basic assemblies are compliant with design specifications, but their effectiveness deteriorates as the assembly's geometrical complexity increases. Automated inspection is desirable because manual inspection by humans is time-consuming, and can be excessively subjective, unreliable, and boring for humans to perform.

A formalism for using 3D imaging for quality control on construction projects was presented in [13]. It focused on detecting defects early in

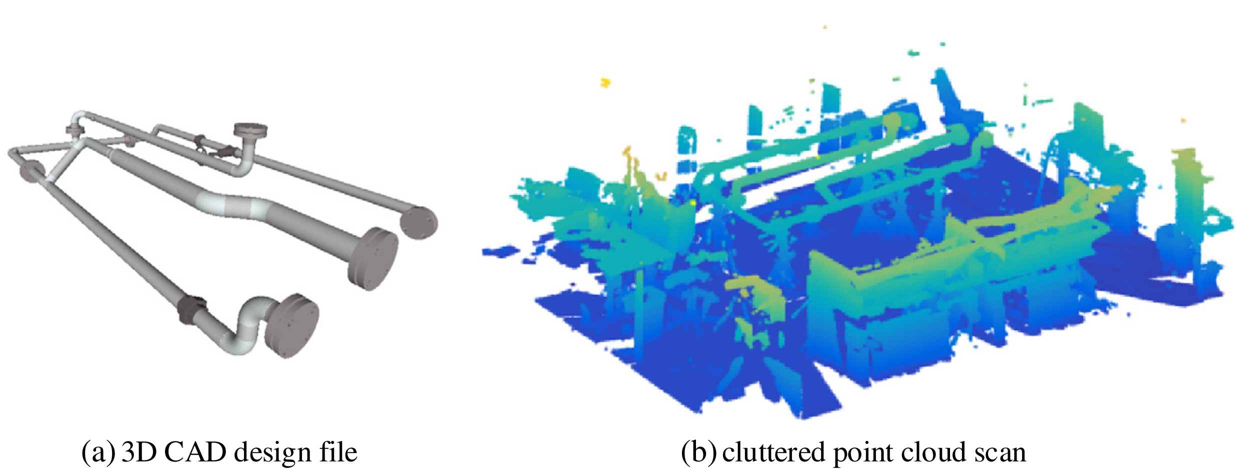

Fig. 2. Search and extraction algorithm input files (a) 3D CAD design file for the object of interest and (b) the raw point cloud scan from which the as-built object of interest will be extracted.