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As-built modeling of piping system from terrestrial laser-scanned point clouds using normal-based region growing

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Abstract

Recently, renovations of plant equipment have been more frequent because of the shortened lifespans of the products, and as-built models from large-scale laser-scanned data is expected to streamline rebuilding processes. However, the laser-scanned data of an existing plant has an enormous amount of points, captures intricate objects, and includes a high noise level, so the manual reconstruction of a 3D model is very time-consuming and costly. Among plant equipment, piping systems account for the greatest proportion. Therefore, the purpose of this research was to propose an algorithm which could automatically recognize a piping system from the terrestrial laser-scanned data of plant equipment. The straight portion of pipes, connecting parts, and connection relationship of the piping system can be recognized in this algorithm. Normal-based region growing and cylinder surface fitting can extract all possible locations of pipes, including straight pipes, elbows, and junctions. Tracing the axes of a piping system enables the recognition of the positions of these elements and their connection relationship. Using only point clouds, the recognition algorithm can be performed in a fully automatic way. The algorithm was applied to large-scale scanned data of an oil rig and a chemical plant. Recognition rates of about 86%, 88%, and 71% were achieved straight pipes, elbows, and junctions, respectively.

Keywords: Laser scanning; Object recognition; As-built model; Piping system; Point clouds

1. Introduction

Recently, because of the short lifespans of plant products, renovations of plant equipment have been more frequent. However, the results of the renovations are not necessarily recorded in the plant drawings in many cases. Thus, unintended collisions between existing equipment and newly designed ones often take place in the construction stage. This causes additional costs and labor.

The performance of terrestrial laser scanners has been rapidly developing, and shapes of objects in environments can be easily captured as 3D point clouds. With these laser-scanned point clouds of existing plants, an as-built model of the plant equipment could be reconstructed. Once the model is reconstructed, the unintended works could be pre-checked on computers and avoided in the planning stage.

However, the laser-scanned data of existing plants have massive point clouds, include a large amount of noise, and capture tangled objects. Therefore, recognizing each plant component from the point cloud, including the tangled objects, and constructing a 3D model of the plants are nearly impossible or very time-consuming when done in an interactive way. Thus, automation of the recognition and 3D model construction processes from point clouds need to be strongly promoted in the plant engineering field.

Plants consist of many types of components. One of the more important components is a piping system, which accounts for the greatest proportion and is renovated frequently. A piping system consists of various elements and their connection relationships: straight pipes, connecting parts such as junctions and elbows, and attached parts such as indicators and valves.

Several studies have been proposed to recognize piping systems from laser-scanned point clouds. However, these algorithms cannot be applied to the point clouds that have already been registered and the intensity, or that can only recognize few classes of piping systems. Masuda et al. [1] proposed a method which could recognize planes and cylinders from the scanned data of plants. However, it required the combination of a scanned point and reflected intensity from a scanner. Rabbaini et al. [2] proposed a method that reconstructed a 3D primitive model from the combination of a point cloud and a photograph taken from the same location. However, the method needed a pair of point cloud data and a photo shot from the scanner position. Piping systems often occupy a broad area of plants, and multiple scans and their

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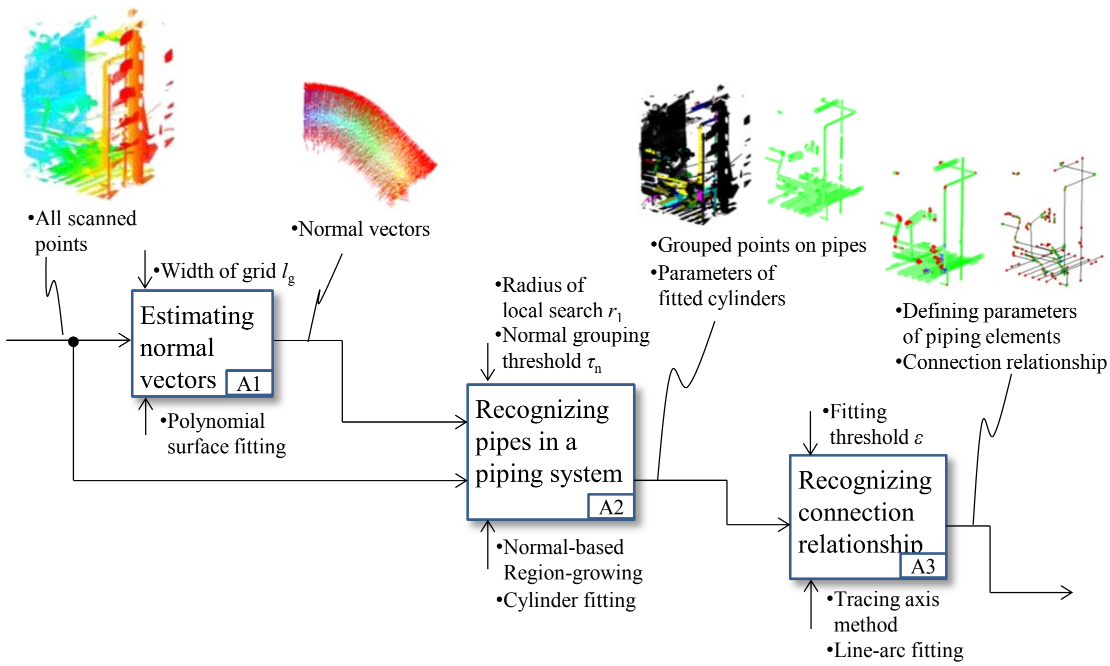

Figure 1. The overview of the proposed piping system recognition algorithm.

registration are inevitable to obtain a point cloud covering the whole shape of the system. Therefore, it is probable that these algorithms cannot be applied to a registered point cloud generated from multiple scans. Aurelien et al. [3] proposed a method which fits an optimized cylinder model to the scanned points using an a priori CAD model of plants. However, 3D cylinder models, which have similar radii and axis directions, have to be placed near the points on pipes manually. Johnson et al. [4] proposed a method which matches a 3D CAD model in a database to a point cloud using a spin image. However, it is difficult to prepare an exact 3D model of straight pipes because their lengths are not fixed. Namatame et al. [5] proposed a method which recognized points on pipes under the assumption of Manhattan World Grammar. However, the algorithm could only recognize the straight portion of a piping system. Recently, Lee et al. [6] proposed a method which recognized straight pipes, elbows, and junctions from points on a piping system using the voronoi diagram. However, in their algorithm, the input point cloud only included the pipes themselves, and did not include any unwanted parts, such as flanges or valves, or supporting members, thus sacrificing generality. Belton et al. [7] and Rabbani et al. [8] proposed methods that classified and partitioned the scanned points of plants into those on planar surfaces and on cylindrical surfaces using covariance analysis and using a combination of normal-based region growing and plane fitting. However, points on elbows and junctions and the connectivity of the piping systems were not identified. Vosselman et al. [9] proposed a method using 3D Hough transforms for recognition. However, only straight pipes are recognized in the piping system. El-Harawany et al. [10] proposed a method that identified cylinders from scanned points of pole-like objects on a road side using a combination of eigen-based segmentation, linear feature extraction, and cylinder fitting. However, if applied to scanned points of plants, only straight pipes could be extracted from them. Marshall et al. [11] proposed a non-linear least-square-based method where scanned points of general objects are segmented into spheres, cylinders, cones, and tori. However, the method dealt only with the point clouds of relatively simple-shaped objects, so it could not work well when applied to the tangled objects in plants.

Therefore, the purpose of this research was to propose a new algorithm that could automatically recognize piping elements consisting of straight pipes and connecting parts and their connection relationships only from raw laser-scanned point clouds of a whole plant, which includes point clouds other than the piping system. The algorithm was tested for large-scale laser-scanned point clouds of a real plant, and the recognition accuracy of the straight pipes and connecting parts were verified.

We have already proposed a similar recognition algorithm of piping systems, but it had some problems [12]. In the process of extracting points on straight pipes, a delicate parameter setting of the searching radius was needed. The parameter should be set in relation to a pipe radius on which the point lies. Therefore, if there is a great distinction among the radii of pipes in the plant, then most of the pipes cannot be extracted. Moreover, the algorithm could not extract some points around non-straight pipes such as supporting materials, attached parts, and junction parts on a straight pipe. Therefore, if tangled pipes are concentrated in a small area, these pipes would not be recognized.

To solve these problems, this paper introduces a normal-