Title:
Reconstruction of Polygonal Faces from Large-Scale Point-Clouds of Engineering Plants

Authors:
Hiroshi Masuda, h.masuda@euc.ac.jp, The University of Electro-Communications
Takeru Niwa, takeru.niwa @euc.ac.jp, The University of Electro-Communications
Ichiro Tanaka, tanaka@cck.dendai.ac.jp, Tokyo Denki University
Ryo Matsuoka, matsuoka@nakl.t.u-tokyo.ac.jp, The University of Tokyo

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Introduction:
The recent progress of mid-range and long-range laser scanners makes it possible to capture dense point-clouds of manufacturing plants. 3D models of manufacturing plants are useful for simulating the reorganizing of production lines, but a raw point-cloud does not have structures suitable for shape manipulation, and the data size is too large to handle for common PCs. Therefore, it is often required to convert point-clouds to simplified mesh models. So far, researchers have studied shape reconstruction of pipe structures by detecting cylindrical surfaces from large-scale point-clouds [1-5]. In the reconstruction of pipes, the shape of a pipe can be easily reconstructed only by estimating the length of the cylinder when a cylindrical surface is extracted.

On the other hand, planar faces may have very complicated boundaries, because surfaces are often be occluded by other surfaces in manufacturing plants. In addition, point-clouds by mid/long-range laser scanners are very noisy and contain a lot of outliers, and the boundary of each planar face becomes a perturbed curve. In this paper, we propose an efficient method for constructing simplified polygonal faces without the loss of detail shapes.

Main idea:
Laser scanners sample points on surfaces using the equal angle spacing. When a laser scanner captures points on a given plane, the distances between points can be easily calculated using the angle spacing and the equation of the plane. For obtaining smooth curves, we define a 2D lattice according to the angle spacing and project each point on the lattice. Then we can obtain boundary pixels and simplify the boundary curves. Our method can recover the structure of original shapes and can greatly reduce the size of mesh models.

Our method consists of the following steps.

(1) Generation of Depth Image: We first project all points captured by a single scan onto a plane and create a 2D range image. Since the directions of laser beams are controlled by the azimuth angle θ and the zenith angle ϕ, (x,y,z) coordinates can be converted to spherical coordinates (r,θ,ϕ), when the origin of the coordinate system is placed at the source of laser beams. Then we can obtain a depth image defined by quantizing angles θ and ϕ, as shown in Fig. 1.

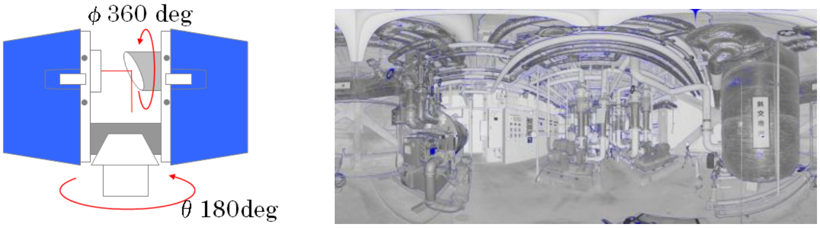


Fig. 1: Depth image defined by two rotating angles.

(2) Detection of Planes: We first segment a depth image and then extract planar regions using the RANSAC method. We segment a depth image by detecting continuous regions. When two neighbor points on a depth image are on the same plane, we can calculate their distance as $s = (\mathbf{p},\mathbf{p})\Delta\phi / |(\mathbf{p},\mathbf{n})|$, where $\mathbf{n}$ is the normal vector of the plane and $\Delta\phi$ is the angle spacing [4]. We estimate that two points are disconnected when their distance is larger than s. For detecting planes, we randomly select three points from each continuous region and calculate the plane equation. Then we search for the largest continuous planar region by traversing pixels on the depth image. When the number of points is larger than a threshold, we regard the continuous planar region as a planar face. We search for faces until no planar faces are found.

(3) Simplification of Boundaries: Boundaries of detected faces are complicated because of noises and occlusions. Fig.2 (Left) shows an example of the boundary of a planar region, which consists of 3774 points. Since the density of points can be estimated using $s = (\mathbf{p},\mathbf{p})\Delta\phi / |(\mathbf{p},\mathbf{n})|$, we generate a 2D lattice with the spacing of $2s$. Then we traverse pixels just like the Marching Cube method, and generate a simplified boundary curve by connecting the centers of boundary pixels. We detect straight-line segments from a sequence of points by using the RANSAC method and further simplify the boundary curves. Finally, we triangulate the closed region, as shown in Fig. 2 (Right).

Our method can efficiently process a large-scale point-cloud. Fig. 3 shows 5624 simplified planar regions, which were detected from about 50 million points. The computation time was 114 second using Intel Core i7 CPU with 12 GB RAM. Fig. 3 (Left) shows detected planes, the middle shows the wireframe, and the right shows planar faces in 3D space.

When planar faces can be detected, solid objects can also be reconstructed by connecting adjacent faces. Fig.3 (Left) shows cuboids reconstructed using a combination of planar faces. Fig.3 (Right) indicates a template of cuboids, which is used to generate structured representation of planar faces for reconstructing solid objects.

Conclusion:

In this paper, we proposed a method for extracting polygonal faces from large-scale dense point-clouds. We first generated a development image using each point-cloud and segmented it into continuous regions. Then we extracted planes using the RANSAC method. We merged polygonal faces extracted from multiple point-clouds. We also showed a method for simplifying rectangle faces. The experimental results showed that our method could generate polygonal faces in a practical time.

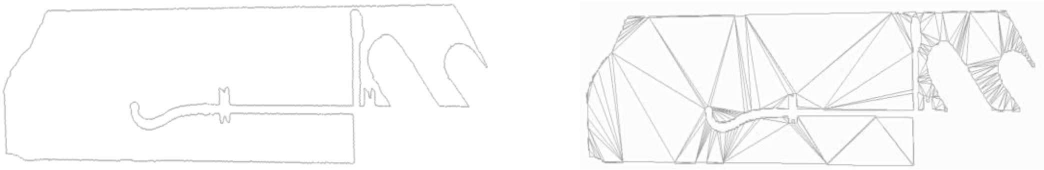
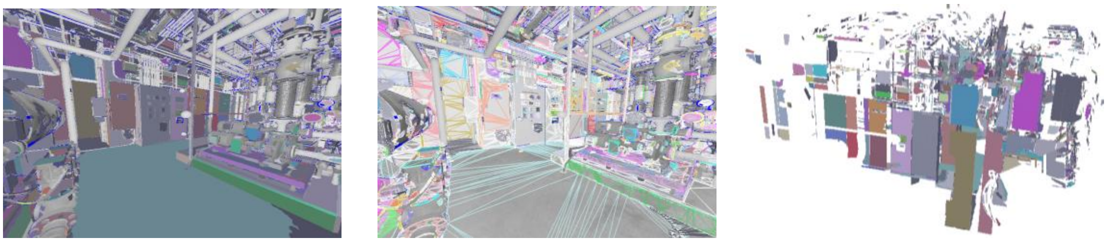


Fig. 2: Simplification of a planar region.



(a) Detected plane (b) Simplified planes (c) Planar faces

Fig. 3: Detected planar faces.

References:

[1] Kawashima, K.; Kanai, S.; Date, H.: As-Built Modeling of Piping System from Terrestrial Laser Scanned Point Clouds Using Normal-Based Region-Growing, 2013 Asian Conference on Design and Digital Engineering, 2013.

[2] Lee, J.; Kim, C.; Son, H; Kim, C.: Skeleton-Based 3D Reconstruction of As-Built Pipelines from Laser-Scanned Data, ASCE International Conference on Computing in Civil Engineering, 2012, 245.

[3] Masuda, H.; Tanaka, I.: Extraction of Surface Primitives from Noisy Large-Scale Point-Clouds, Computer-Aided Design and Applications, 6(3), 2009, 387-398. http://dx.doi.org/10.3722/cadaps.2009.387-398

[4] Masuda, H.; Tanaka, I.; Enomoto, M.: Reliable Surface Extraction from Point-Clouds using Scanner-Dependent Parameters, Computer-Aided Design and Applications, 10(2), 2012, 265-277. http://dx.doi.org/10.3722/cadaps.2013.265-277

[5] Mizoguchi, T.;Kuma, T.; Kobayashi, Y.; Shirai, K.: Manhattan-World Assumption for As-Built Modeling Industrial Plant, Key Engineering Materials, 523, 2012, 350-355. http://dx.doi.org/10.4028/www.scientific.net/KEM.523-524.350