ISPRS Journal of Photogrammetry and Remote Sensing 102 (2015) 172–183

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Line segment extraction for large scale unorganized point clouds

Yangbin Lin [a], Cheng Wang [a,*], Jun Cheng [a], Bili Chen [b], Fukai Jia [a], Zhonggui Chen [a], Jonathan Li [c]

[a] *Fujian Key Laboratory of Sensing and Computing for Smart Cities, Department of Computer Science, Xiamen University, Xiamen, FJ 361005, China*
[b] *School of Software, Xiamen University, Xiamen, FJ 361005, China*
[c] *Department of Geography & Environmental Management, University of Waterloo, Waterloo, ON N2L 3G1, Canada*

ARTICLE INFO

Article history:
Received 28 May 2014
Received in revised form 18 December 2014
Accepted 19 December 2014

Keywords:
Line segment extraction
3D line-support regions
Point clouds
LiDAR
Mobile laser scanning
3D Structure

ABSTRACT

Line segment detection in images is already a well-investigated topic, although it has received considerably less attention in 3D point clouds. Benefiting from current LiDAR devices, large-scale point clouds are becoming increasingly common. Most human-made objects have flat surfaces. Line segments that occur where pairs of planes intersect give important information regarding the geometric content of point clouds, which is especially useful for automatic building reconstruction and segmentation. This paper proposes a novel method that is capable of accurately extracting plane intersection line segments from large-scale raw scan points. The 3D line-support region, namely, a point set near a straight linear structure, is extracted simultaneously. The 3D line-support region is fitted by our Line-Segment-Half-Planes (LSHP) structure, which provides a geometric constraint for a line segment, making the line segment more reliable and accurate. We demonstrate our method on the point clouds of large-scale, complex, real-world scenes acquired by LiDAR devices. We also demonstrate the application of 3D line-support regions and their LSHP structures on urban scene abstraction.

1. Introduction

Benefiting from the advances in sensor technology for both airborne and ground-based mobile laser scanning, dense points clouds have become increasingly common, and the need for new approaches to address these point clouds has become increasingly important. As the common feature in man-made objects, straight linear structures play an important role in a variety of applications, such as: road extraction (Yang et al., 2013); building outline extraction (Baillard et al., 1999); localization (Borges et al., 2010), city model building (Lafarge and Mallet, 2012); calibration (Moghadam et al., 2013); line-based visualization (Chen and Wang, 2011); and more. This paper emphasizes straight line segment extraction for point clouds, whereas most of the existing work concentrates on 2D line segment detection in a single image (Ballard, 1981; Burns et al., 1986; Von Gioi et al., 2010) and 3D line segment reconstruction in multi-view images (Baillard et al., 1999; Woo et al., 2009; Jain et al., 2010). Only a few papers consider point clouds (Lu et al., 2008; Moghadam et al., 2013).

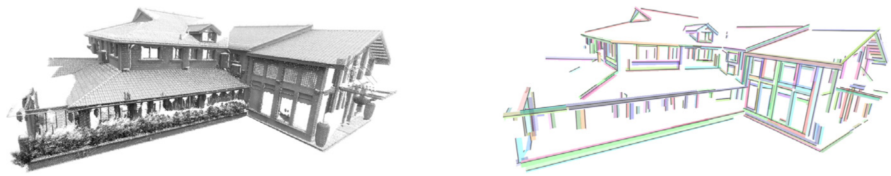
A large number of dense point clouds have been obtained by current scanners; the RIEGL VMX-450 scanner, for example, can yield 1.1 million range measurements per second. Therefore, one of the biggest challenges is to find an efficient way to address the voluminous data. Unorganized point clouds lack normal vector and connectivity information, making the problem even more challenging.

Our method is designed to cope with line segment extraction for large-scale unorganized point clouds from the real word. A line segment here is defined as the intersection of two half-planes. To extract the line segment, we take into account the point region that is near the straight linear structure. Such a region is designated as a "3D line-support region." The word "3D" is used to distinguish the region from the concept of a "line-support region," which has proved to be a robust descriptor to extract line segments in images.

The key idea of our method is to first convert a point cloud into a collection of shaded images by non-photorealistic rendering with different viewpoints; then the LSD algorithm (Von Gioi et al., 2010) is applied to these images to extract the 2D line-support regions. These 2D line-support regions are then back-projected into the original point cloud as 3D line-support regions, with each region containing roughly one line segment. Next, to maintain accuracy, each 3D line-support region is fitted by our Line-Segment-Half-Planes (LSHP) structure. Finally, the 3D line-support regions and their LSHP structures are refined as the output.

* Corresponding author.
E-mail address: cwang@xmu.edu.cn (C. Wang).

http://dx.doi.org/10.1016/j.isprsjprs.2014.12.027



(a) 3D raw scan point cloud (rendered by ambient occlusion). (b) Extracted 3D line segments with attached half-planes.

Fig. 1. Given an unorganized 3D raw scan point cloud (a), our method is able to extract line segments together with attached half-planes (b), where the line segments are drawn in black color and their attached half-planes are represented by colored 3D rectangles. (a) 3D raw scan point cloud (rendered by ambient occlusion). (b) Extracted 3D line segments with attached half-planes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

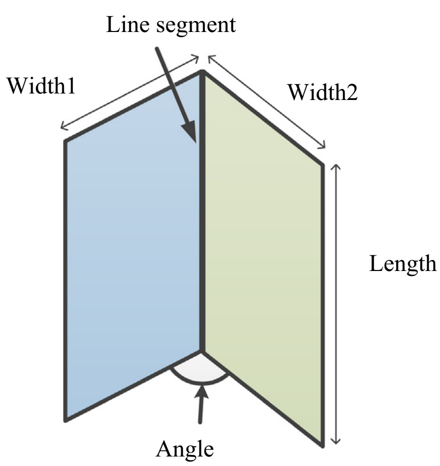


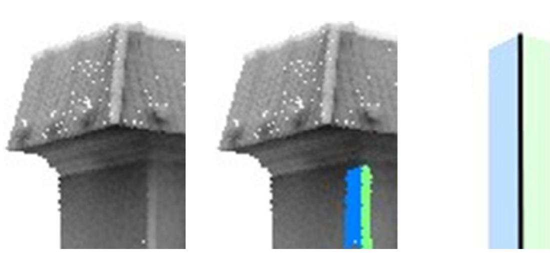
Fig. 2. Line-Segment-Half-Planes (LSHP) structure is characterized by two tangential 3D rectangles.

Fig. 1 presents a result of our method. Given an unorganized 3D raw scan point cloud as the input (Fig. 1(a)), our method extracts the 3D line-support region and LSHP structures as the output, where the line segments are drawn in black and the attached half-planes are represented by colored 3D rectangles (Fig. 1(b)). As a result, the LSHP structure provides an abstraction of a point cloud, and the vegetation in the input is filtered.

2. Related work

2.1. 2D line segment detection for a single image

Image line segment detection has been studied over several decades. The traditional methods combine the Canny edge detector (Canny, 1986) and Hough transform (Ballard, 1981). These methods are generally slow and produce a significant number of false detections. Recently, an efficient line segment detector with false detection control (designated LSD) was presented by Von Gioi et al. (2010). LSD follows the method proposed by Burns et al. (1986). First, the image is partitioned into a collection of straight image regions, named line-support regions; the gradient angles of pixels in each region are roughly oriented along the same direction. Then, a line segment, that best approximates each line-support region, is determined. Finally, a line segment validation, based on the approach of Desolneux et al. (2000) is adopted to control the number of false detections.



(a) (b) (c)

Fig. 3. Example of 3D line-support region and its Line-Segment-Half-Planes (LSHP) structure. (a) Raw scan point cloud. (b) One of the 3D line-support region. (c) The reconstructed LSHP structure of the 3D line-support region in (b).

2.2. 3D line segment reconstruction from multi-view images

Numerous papers on 3D line segment reconstruction for multi-view images have been published in recent years. Taylor and Kriegman (1995) presented a reconstruction algorithm that works by minimizing an objective function that is defined as the total squared distance between the observed edge segments from the image and the projections of the reconstructed lines. Baillard et al. (1999) found the correspondence between lines over stereo images by epipolar geometry and cross correlation scores. Then the attached half-planes are computed for piecewise planar reconstruction of the 3D model. Heuel and Forstner (2001) combined projective geometry and a statistical hypotheses test to reconstruct the 3D line segments. Martinec and Pajdla (2003) reconstructed lines by factoring a matrix containing line correspondences. Jain et al. (2010) used connectivity constraints to reconstruct the line segments from different stereo images independently; the partial reconstructions are then merged into a global result. Chen and Wang (2011) first detected 2D line segments from photos and generated a 3D point cloud by the Structure From Motion (SFM) methods (Snavely et al., 2006). Then, the 3D lines are reconstructed by applying the weak matching method both on 2D photos and a 3D point cloud. The false 3D line segments are filtered via a plane-clustering algorithm. Ceylan et al. (2012) generated 3D lines from image-level edges of urban buildings and then used these lines to simultaneously detect symmetric line arrangements while refining the 3D building model.

Most of the above algorithms use line matching to reconstruct 3D lines. Generally speaking, line matching is a difficult task due to its lacks of geometric constraints. In contrast, via our approach, the images are generated from a point cloud. Because depth information is already known, our approach does not need to apply line matching between multiple images.

2.3. Line segment detection for 3D point clouds

Few papers concentrate on line segment detection for 3D point clouds. Lu et al. (2008) combined the RANdom SAmple Consensus (RANSAC) method and Mahalanobis distance to detect 3D lines.