A Voxel- and Graph-Based Strategy for Segmenting Man-Made Infrastructures Using Perceptual Grouping Laws: Comparison and Evaluation

Yusheng Xu, Ludwig Hoegner, Sebastian Tuttas, and Uwe Stilla

Abstract

In this paper, we report a novel strategy for segmenting 3D point clouds using a voxel structure and graph-based clustering with perceptual grouping laws. Two different segmentation methods using voxel and supervoxel structures are presented and evaluated. To increase the efficiency and the robustness of the segmentation process, the voxelization with octree-based structure is introduced, which can suppress effects of noise, outliers, and unevenly distributed point densities as well. The clustering of over-segmented voxels and supervoxels is achieved using graph theory on the basis of the local contextual information, which is commonly conducted merely with pairwise information in conventional clustering algorithms. The graphical model is constructed according to perceptual grouping laws, considering geometric information associated with points. Experiments using both laser scanning and photogrammetric point clouds have demonstrated that the proposed methods can achieve good results, especially complex scenes and nonplanar object surfaces, with F1-measures better than 0.67 for all the testing samples. Quantitative comparisons between the proposed approaches and other representative segmentation methods also confirm the effectiveness and the efficiency of the former. Moreover, a series of experiments is carried out, to investigate the methods’ sensitivity with respect to various parameters on the segmentation results.

Introduction

In recent years, the reconstruction of 3D scenes using point clouds obtained from laser scanning, stereo matching, and range imaging cameras is attracting increasing attention for many tasks such as constructing virtual reality, creating digital surface models, or monitoring construction projects. In such settings, point clouds are considered to be suitable data sources for recognizing and reconstructing geometric objects from 3D scenes. In general, individual objects should be identified and separated from the scene prior to the recognition or modeling procedure. This is because the majority of both indoor and outdoor scenes usually contain different types of objects, complex structures, and surfaces of various shapes, so that it is hard to directly recognize or model certain kinds of objects from the scene (Yang et al., 2015). To this end, for unstructured raw point clouds, segmentation is a fundamental step and commonly applied to partition the 3D scene into the largest possible meaningful segments, namely groups of points having one or more characteristics in common (Grilli et al., 2017; Vosselman et al., 2017).

Theoretically, a well thought-out segmentation algorithm can remove irrelevant objects in the scene and largely lessen the burden of workloads of computing and storing. However, the performance of conventional point cloud segmentation algorithms commonly deteriorates in complex environments of real outdoor scenes, especially for scenes containing buildings, where occlusions frequently occur. Such complex scenes degrade the performance of commonly used methods, because most of the segmentation criteria use merely pairwise information between elements (e.g., differences of normal vectors calculated from points), which is sensitive to missing points and incomplete structures caused by occlusions. Moreover, the data quality is also a leading cause for erroneous segmentation results. For instance, outliers and unevenly distributed points densities significantly affect the boundary quality of segments owing to wrongly estimated point-based geometric features (e.g., normal vectors or local density). Hence, apart from the effectiveness, the reliability should be considered in the development of segmentation algorithms as well. On the other hand, as point cloud segmentation is computationally intensive, efficiency is also relevant and should be taken into consideration when having to cope with large datasets.

To tackle the aforementioned problems, we propose a point cloud segmentation strategy to efficiently acquire geometric segments from large-scale point clouds of man-made scene. In Figure 1, we give an illustration of how the point cloud of the scene is segmented. Here, the entire point cloud of the scene is split into individual segments related to semantic objects.