Salient Feature Detection for 3D LIDAR Registration

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***Abstract*—In this paper we propose a novel detection algorithm SKIP-3D (SKeleton Interest Point) for extraction of edges from multi-layer LIDAR scans. SKIP-3D exploits the organization of LIDAR measurements to search silent points in each layer through an iterative bottom-up procedure, removing low curvature points. The edge features from two point clouds are associated and used for their alignment. The experimental results shows that the proposed approach is efficient and reliable.**

I. Introduction

In last years, multi-layer LIDAR sensors have been attracting increasing interest due to their capability to acquire real-time three-dimensional range data in outdoor scenarios and large-scale environments and their continuously decreased cost. LIDARs, such as Velodyne VLP-16, HDL or Ouster OS-1 series, can measure ranges of over 25 meter with 360 degree horizontal field-of-view (FoV) and accuracy of few centimeters. The potential applications include localization, 3D mapping, object tracking and navigation especially in contexts like autonomous driving, construction sites and industrial warehouses and plants.

The main issues of multi-layer LIDARs are due to their unequal horizontal and vertical sampling and to the large amount of real-time measurements to be processed and managed. While the horizontal angular resolution is high and covers 360 degree, the vertical one depends on the usually limited number of layers and cover a limited FoV. The sparsity of the point cloud obtained from LIDAR scan should be taken into account in registration between different views and, particularly, in point association. Such a problem can be addressed by approaches based on feature detection, which have also improve efficiency through data compression. However, measurement sparsity and unequal resolution make feature detection difficult even in case of simple edges and planes. While there is large literature about point cloud registration, the works about sparse point cloud alignment and, in particular, multi-layer LIDARs are limited. A significant work described in [1] presents a LIDAR 3D registration and mapping system that uses temporary high curvature points as features. Such point features enable effective alignment, but are not descriptive enough for medium or long term mapping. IN2LAMA system [2] is likely the closest work to our goal. It extracts points, lines and planar patches from LIDAR scans and aligned them by minimizing the proper distance functions among feature pairs. All the discussed works do not take explicit advantage of the organization of point clouds acquired by multi-layer LIDARs. Each range measurement belong to a specific layer (also known as ring) of the scan and the measurements of each layer are radially ordered leading to array indexing. Such organization could be exploited for efficient detection of salient features to be used in small footprint maps.

In this paper, we propose a novel detection algorithm SKIP-3D (SKeleton Interest Point) for extraction of edges from multi-layer LIDAR scans. SKIP-3D exploits the organization of LIDAR measurements for finding number of points on the target of interest. The algorithm operates on each layer of the scan to find salient points according to a bottom-up procedure that iteratively remove at each step the least significant point. A score function related to the curvature in a layer is used to evaluate point significance. The algorithm carefully treat gaps due to occlusion and sensor limitations. Then, the neighbor salient points across the layers are matched in order to find edge features. Edges are both characterized by parameters (segment end-points, line parameters) and the list of salient points belonging to the edge. The edge features extracted from two different point clouds can be associated and aligned by minimizing the cumulative edge distance. In the following, we illustrate the details of the algorithm.

II. Detection SKIP-3D

The proposed feature extraction algorithm is based on curve simplification on the point of a LIDAR layer. Let $\mathbf{p}_{li}$ be a generic point of the cloud in layer l and layer index i. Ideally, each $\mathbf{p}_{li}$ has a previous point $\mathbf{p}_{l,pv_i}$ and a next $\mathbf{p}_{l,nt_i}$ in a circularly linked list representing the layer. Such indices are initialized as $pv_i = i - 1 \ (mod\ n)$ and $nt_i = i + 1 \ (mod\ n)$. The exceptions are the gap points, i.e. points in strong range discontinuities due to occlusion and limitations of the FoV. Hence, a layer is not represented by a closed curve and the points lying on the gap are removed from the list of potential salient points. The saliency score of a point is given by triangular residual: given $d_{P,i} = \|\mathbf{p}_{l,pv_i} - \mathbf{p}_{l,i}\|$, $d_{N,i} = \|\mathbf{p}_{l,nt_i} - \mathbf{p}_{l,i}\|$ and $d_{C,i} = \|\mathbf{p}_{l,nx_i} - \mathbf{p}_{l,pv_i}\|$, the score $s_i = d_{P,i} + d_{N,i} - d_{C,i}$. The candidate salient points, excluding gap points, are inserted into a priority queue $\mathcal{Q}$

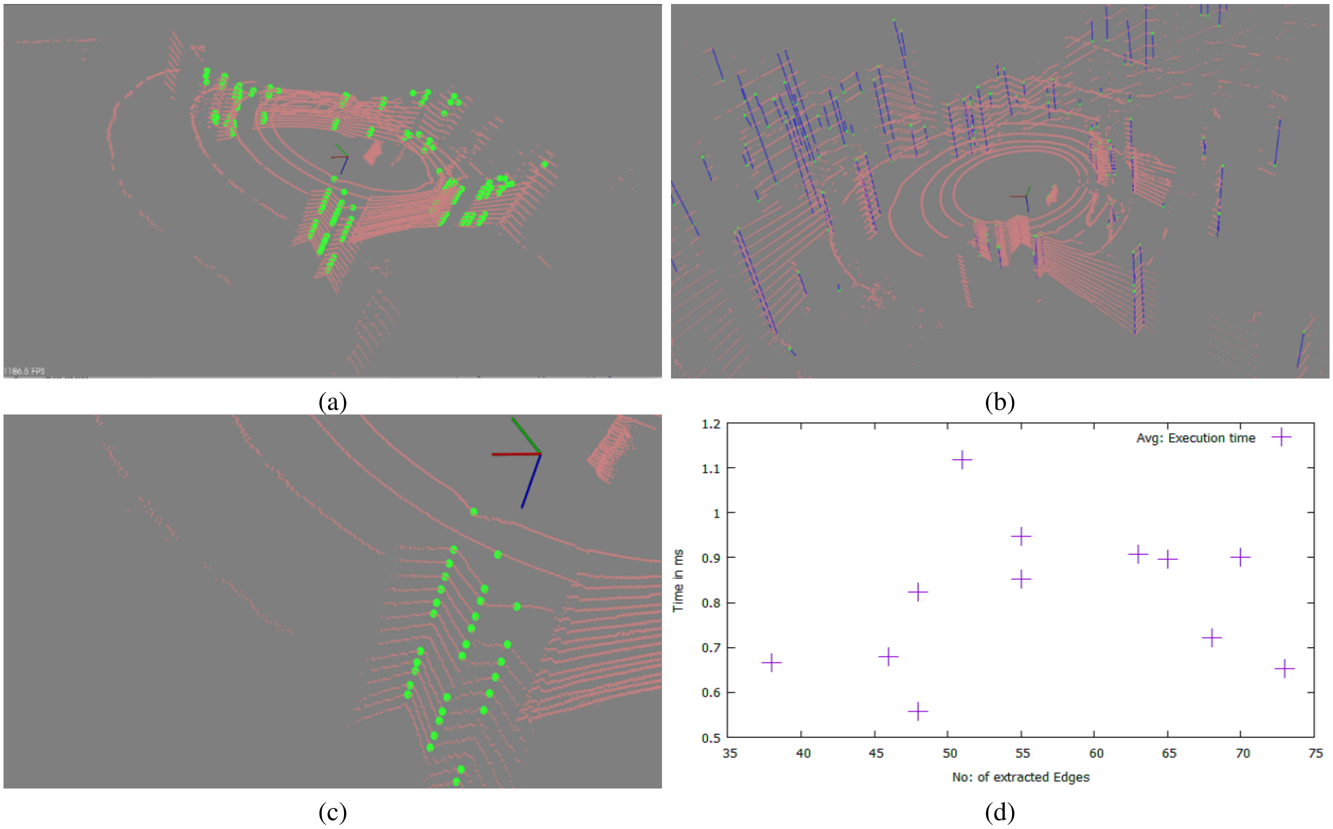

Fig. 1: Example of SKIP-3D: the salient points corresponding to the edges (a), the SKIP-3D edges with their endpoints (b), particular of extracted edges (c), Total number of extracted edges vs average execution time (d).

ordered according to the score (minimum score first). At each iteration the algorithm removes the least significant point $p_{l,i}$ from $\mathcal{Q}$ until its score is less than a given threshold. After a removal the previous and next points of neighbors change as well as the scores and they must be updated. Figure 1(a) shows an example of salient points.

The list $\mathcal{L}$ of salient points extracted on each layer are arranged into a single list sorted in lexicographic order according first to azimuth index i and then to the layer one l. The list $\mathcal{L}$ is visited and the close points in each layer are grouped into a single set. An edge s is defined by the set of points $\mathcal{E}_s$ and its line parameters computed through last-square regression (the line direction vector $\mathbf{d}_s$ with $\|\mathbf{d}_s\|$ equal to the length of the segment and endpoint $\mathbf{r}_s$). Figure 1(b) shows the edges extracted from a point cloud.

The registration of two point clouds is achieved by associating their corresponding edges and minimizing the sum of square distances. For limited viewpoint changes, standard nearest neighbor association allows the matching of corresponding edges, but more sophisticated approached could be applied. The standard solution of Procrustes problem cannot be used in this case, since a point-to-line metric is used. The optimal rotation $\mathbf{R}$ and translation $\mathbf{t}$ is s.t. the distances between each point $\mathbf{s}_k \in \mathcal{E}_s^S$ of the source edge transformed into $\mathbf{R}\mathbf{s}_k + \mathbf{t}$ and the corresponding destination edge $\mathcal{E}_s^D$ identified by endpoints $\mathbf{d}_{F,s}$ and $\mathbf{d}_{L,s}$. The objective function consists of the average of the average distances between source points and the segment.

Preliminary experiments are conducted based on datasets collected in the department hallways using a mobile robot equipped with Velodyne VLP-16. The acquisition of point cloud took place every 50 cm of distance traveled in the corridor of the university department. The statistics about the execution times w.r.t. the number of all extracted edges in a point cloud are shown in Figure 1(d). On average the algorithm requires less than 1 ms.

III. Conclusion

In this paper, the organized structure of LIDAR 3D scan is exploited for the detection of edges from point cloud. Preliminary tests for target feature extraction from point cloud shows the effectiveness of our approach for the extraction of interesting edges. In future works, we expect to develop a complete registration and mapping system and to use other features.

References

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