Reliable Normal Estimation from Sparse LiDAR Point Clouds

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Abstract--In this paper, we present a reliable vertex normal estimation method from sparse point clouds that improves the accuracy of plane-based frame-to-frame registration. We define a face normal reliability measure. The vertex normals are calculated by weighted averaging adjacent face normals based on the reliability. Through the experiments, it is confirmed that the proposed method produces consistent and reliable vertex normals.

I. INTRODUCTION

Recently, LiDAR-based perception systems have been widely utilized alongside the development of autonomous driving and autonomous robotics applications. LiDAR devices provide depth measurements of their surroundings, making them usually the first choice for environmental sensing. LiDAR devices rotate multiple laser beams to extract 360° view. Since a frame, the point data obtained through a single revolution of the beams, contains around 30,000 points, the data rates become a nearly 3MB per second. Nonetheless, these fixed number of discrete beams result in quite sparse point clouds in far away distance as shown in Fig. 1. The noisy point data is dense in the azimuthal direction, while relatively very sparse between beam rings.

Although 3D point cloud processing methods have achieved significant process in many fields such as segmentation, frame-to-frame registration and SLAM [1], such sparsity of LiDAR point clouds makes space adjacency based methods powerless, since there are not enough points to guarantee the local structure information, or not enough neighbor grids to represent the local space information.

Vertex normals are very important for 3D point cloud processing methods such as surface reconstruction [2],[3], ICP-based frame-to-frame registration [4], because they can provide the shape of surfaces. For a vertex, its normal can be obtained by estimating a local surface using principal component analysis with its k-nearest neighboring vertices [2]. However, in the sparse LiDAR point clouds, the k vertices would be selected along the azimuthal direction as shown in Fig. 1. In that case, the local surface cannot be inferred correctly.

In the geometry of computer graphics, a vertex normal is computed as the normalized average of the normals of the faces that contain that vertex. The average can be weighted by the area of the face [5]. However, noises and outliers in the LiDAR point clouds cause inaccurately modelled surfaces. As a result, averaging face normals gives unsatisfactory results.

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Because of vertex normal estimation, \( \gamma = f_n \cdot \nabla \), where \( f_n \) and \( \nabla \) indicate the center of the face \( f \) and the inner product, respectively. \( \gamma \) significantly reduces if the face normal becomes orthogonal to the direction of the incident laser beam as in the case of the meaningless faces. Fig. 3 illustrates the relation of the face normals and the laser beam direction. The sky blue triangle represents meaningless faces.

Finally, the vertex normals \( n_i \) are calculated as

\[
\gamma_i = \left| f_{n_i} \cdot \frac{f_c}{\|f_c\|_2} \right|,
\]

where \( f_c \) and \( \cdot \) indicate the center of the face \( f \) and the inner product, respectively.

In order to utilize reliable face normals, we define a face normal reliability measure \( \gamma_i \) as follows:

\[
\gamma_i = \left| f_{n_i} \cdot \frac{f_c}{\|f_c\|_2} \right|,
\]

where \( f_c \) and \( \cdot \) indicate the center of the face \( f \) and the inner product, respectively.

Next, the vertex normals \( n_i \) are calculated as

\[
n_i = \sum_{j \in N_i} y_j f_{n_j},
\]

where \( N_i \) represents the set of the indices of faces that have \( v_i \).

B. Vertex Normal Estimation

It is notable that the mesh obtained using the LiDAR frame data contains faces that just connect objects of different distances rather than represent actual object surfaces. Because such meaningless faces have large areas and irrelevant face normals, the conventional vertex normal estimation methods may produce noisy and unreliable vertex normals.

In order to utilize reliable face normals, we define a face normal reliability measure \( \gamma_i \) as follows:

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III. EXPERIMENTAL RESULTS AND CONCLUSIONS

The proposed vertex normal estimation method was compared to two conventional methods; the method using \( k \)-nearest neighbor vertices and the method averaging neighboring face normals that are referred to as \( k \)-neighborhood and face normal averaging, respectively.

Fig. 4 visualizes calculated vertex normals of the box in the scene. The box consists of three orthogonal planes represented in different face colors. The \( k \)-neighborhood method failed to infer local planar structures from sparse point clouds, and thus, produced all upward vectors. The face normal averaging method yielded better results than the \( k \)-neighborhood method, but the normals were inconsistent and noisy. Especially, the normals on the mesh boundary were inaccurate due to the influence of meaningless faces. The normals obtained using the proposed method were more consistent, since the proposed measure \( \gamma_i \) successfully evaluated reliability of the face normal.

Fig. 5 depicts point cloud merging results that were obtained using an iterative closest point (ICP)-based registration method with the three different vertex normals. A plane representing the ceiling in the scene was seen in tangential direction as indicated by the red camera frame in the left image. Eight point clouds were aligned inadequately using the normals obtained by the \( k \)-neighborhood method. For the face normal averaging and the proposed method, the projected ceiling looks linearly. However, the proposed method produced less perturbation.

We presented the vertex normal estimation method that utilizes face normals based on the face normal reliability. Vertex normal visualization confirmed that the proposed method produced consistent and reliable normals. More accurate point cloud registration can be achieved using the normals obtained by the proposed method.

REFERENCE


