博 士 論 文 の 内 容 の 要 旨

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（博士論文の内容の要旨）

Recently, with the advent of low-cost 3D sensing technology, the need for processing, analyzing, and detecting patterns in 3D point clouds has been getting the focus of industry and the academy.

Assistant robots and the introduction of intelligent robotics in the industry will play a major role in how well we address population aging and even disaster prevention and management. In reverse engineering, we are able to create new pieces without blueprints. The acquisition of 3D point clouds and the detection of its geometry are crucial to numerous applications.

One main characteristic of urban environments and man-made objects is their geometric nature. They are comprised of several geometric shapes such as planes, spheres, and cylinders. Due to their broad applications, detecting them is an important task in 3D point cloud processing. However, their detection in point clouds is not trivial.

The first part of this thesis focuses on describing different 3D sensing technologies and the characteristics of their resulting point clouds as well as the discussion of geometric primitive detection.

Conventional geometric primitive detection algorithms rely on the correct estimation of local features such as normal vectors. In most cases, their efficient and correct computation is not yet possible. RANSAC based methods and the Randomized Hough Transform (RHT), use random sampling to find hypothetical models faster. In RANSAC based methods, deficiencies arise with a poor inliers/outliers ratio, which is a common scenario in high-range sensors or even low-cost sensors due to noise. Sometimes, the iterations are not enough to detect shapes diminishing their efficiency and accuracy.

Hough Transform methods suffer from the quantization of their accumulator, they need to rely on further refitting the detected shapes during the voting process. Moreover, for 3D shapes, it is only defined for planes since an accumulator of more than 3 dimensions would need an unfeasible amount of memory.

In the first part of this thesis, I explain the basic concepts behind 3D sensors. Therefore, in this thesis, I focus on solving the problem of geometric primitive detection in 3D point clouds.

As planes are the most common geometric primitive, the second part of this thesis focus on a more efficient approach for plane detection: the Fast and Deterministic Hough Transform based plane detector (FDHT). The key for its efficiency is that we opted for analyzing fewer voxelized regions as opposed to pixel-wise neighborhoods to detect planes. Points are filtered using a Scaled Difference of Normals (SDoN) over these voxels. Then, instead of random sampling, the proposed plane detector analyzes deterministically the whole point cloud with higher efficiency.

Because the detection mechanism is based on Hough voting, I proposed a novel memory model for the accumulator based on nested trees instead of contiguous arrays to avoid memory saturation in Hough space. Nevertheless, it still requires improvement in robustness and efficiency since it needs a pre-filtering mechanism (SDoN) which adds computational complexity.

Therefore, based on existing knowledge about sliding windows in object detection, in the third part of this thesis, I propose a novel plane detector approach based on sliding voxels.

Instead of analyzing independent voxels of the point clouds, overlapping voxelized regions of the point cloud. A 3x3x3 sliding voxel is defined for each voxelized region in the point cloud. An efficient non-planar filtering method can be performed simultaneously while the sliding voxels are sorted by their planarity. These planar regions define hypothetical planes that are sorted by their number of inliers. Finally, by removing planes from bigger to smaller we can detect planes with superior robustness and efficiency. Experiments from realistic point cloud simulations show that the proposed sliding voxel plane detector is drastically more efficient and robust than the state-of-the-art planes detectors.

Since the main key of the sliding voxel algorithm is its efficiency generating hypothetical models from point clouds. We explored this paradigm to sphere detection.

As opposed to planes, which are simple and linear geometric models, spheres are closed surface quadrics. The sliding voxel for sphere detection provides an efficient local sphere fitting algorithm that gets the most probable sphere at each sliding voxel using robust statistics. This allows us to robustly generate hypothetical spheres with high efficiency. For each hypothetical sphere, Hough voting is performed on a 4D sparse accumulator to detect the most prominent spheres. After extracting spheres from the accumulator, the algorithm refits them and filter by a novel measure of completeness.

The sliding voxel sphere detector has drastically higher efficiency while being more precise than the conventional method in realistic point cloud simulations. It demonstrated superior robustness by keeping its high accuracy while increasing Gaussian noise. Furthermore, it shines when processing LIDAR point clouds. They tend to be massive and with high range; hence, their number of model outliers are overwhelming for methods based on random sampling. There, the proposed sphere detector had not only superior efficiency but its accuracy was exceptionally high.

The sliding voxel paradigm showed that we can design highly efficient and robust shape detectors. Further works in the detection of arbitrary shapes is a promising line of research that opens from this thesis.