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主論文の要旨

論文題目　**3D Mapping and Modeling based on Data Fusion of LiDAR and Panoramic Camera**
(LiDAR と全方位カメラのデータ融合に基づく三次元マッピングとモデリングに関する研究)

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論文内容の要旨

Fusion of Light Detection And Ranging (LiDAR) and camera data has brought huge benefits in various applications such as autonomous driving and 3D mapping. As the first and critical step for fusing multi-modal data, extrinsic calibration of sensors has been a classic problem in the fields of computer vision, robotics and remote sensing. Earlier works including offline and online methods of extrinsic calibration of LiDAR-Camera system either need manual intervention, initial guess or lack robustness and accuracy. On the other hand, the sheer volume of 3D data after mapping multiple frames of point clouds contain enormous redundant information which makes it a challenge to efficiently view, manipulate and store them. Therefore, representation with semantic extraction or geometric primitives reconstruction is needed for simplification. Moreover, surface reconstruction is able to bring better visualization. This dissertation presents novel methods including segmentation of a single sparse point cloud, incremental segmentation of multiple frames of point clouds, extrinsic calibration of LiDAR-Camera system and 3D modeling and surface reconstruction of the point cloud.

Chapter 1 introduces the background and motivation of this work as well as the scope discussed in this work. The issues to address in this work are also stated. To address these open problems, novel methods proposed are listed. Finally, the structure of this dissertation is described.

Chapter 2 states the recent 3D mapping technologies and related works to this research. 3D mapping technologies with LiDAR sensors, especially 3D mobile LiDAR sensors, are introduced. After the introduction of LiDAR sensors, related works to segmentation, extrinsic calibration and surface reconstruction are presented respectively.

Chapter 3 describes the system used for data acquisition and the datasets for developing and evaluating the algorithm in this work. To make the proposed methods for processing point cloud data easier to explain, the datasets are first presented in this chapter. Since there is no suitable open dataset for our methods, a mobile system for data acquisition is proposed, and the sensors' setup is showed. With the mobile system, datasets are collected from different environments. Details about acquired datasets as well as the open dataset we used for evaluation in this work are introduced.

Chapter 4 explains the scanline-based method segmentation for sparse point cloud and the incremental segmentation scheme. To accomplish the convenient extrinsic calibration method for LiDAR-camera system, automatic detection of the chessboard from the point cloud needs to be done first. In other words, the point cloud of the chessboard needs to be segmented from the single frame of the point cloud. A single frame of the point cloud obtained by 3D LiDAR is usually sparse. On the other hand, the segmentation of point clouds is an important aspect of automated processing tasks, such as semantic extraction for abstract representation. However, the sparsity and non-uniformity of the point clouds gathered by the popular 3D mobile LiDAR devices pose many challenges for existing segmentation methods. To improve the segmentation results of point clouds from mobile LiDAR devices, we propose an optimized segmentation method based on Scanline Continuity Constraint (SLCC). Unlike conventional scanline-based segmentation methods, SLCC clusters scanlines using the continuity constraints in terms of the distance as well as the direction of two consecutive points. In addition, scanline clusters are agglomerated not only into primitive geometrical shapes but also irregular shapes. Another downside to existing segmentation methods is that they are not capable of incremental processing; this causes unnecessary memory and time consumption for applications that require frame-wise segmentation or when new point clouds are added. In order to address this, we propose an incremental scheme—the Incremental Recursive Segmentation (IRIS), that can be easily applied to any segmentation method. IRIS is achieved by combining the segments of newly added point clouds and the previously segmented results.

Chapter 5 describes the novel intensity-based extrinsic calibration method for LiDAR-Camera system. After the segmentation process for the point cloud, a fully automatic and convenient extrinsic calibration of a 3D LiDAR and a panoramic camera with a normally printed chessboard is proposed. The proposed method is based on the 3D corner estimation of the chessboard from the sparse point cloud generated by one scan of the LiDAR. To estimate the corners, we formulate a full-scale model of the chessboard and fit it to the segmented 3D points of the chessboard. The model is fitted by optimizing the cost function under constraints of correlation between the reflectance intensity of laser and the color of the chessboard's patterns. Powell's method is introduced for resolving the discontinuity problem in optimization. The corners of the fitted model are considered as the 3D corners of the chessboard. Once the corners of the chessboard in the 3D point cloud are estimated, the extrinsic calibration of the two sensors is converted to a 3D-2D matching problem. The corresponding 3D-2D points are used to calculate the absolute pose of the two sensors with Unified Perspective-n-Point (UPnP). Following that, the calculated parameters are regarded as initial values and are refined using the Levenberg-Marquardt method. The performance of the proposed corner detection method from the 3D point cloud is evaluated using simulations. The results of experiments, conducted on a Velodyne HDL-32e LiDAR and a Ladybug3 camera under the proposed re-projection error metric, qualitatively and quantitatively demonstrate the accuracy and stability of the final extrinsic calibration parameters.

Chapter 6 shows the further processing for colored 3D mapping and surface reconstruction. We get the RGB information of the point cloud from the corresponding panoramic image with the estimated extrinsic parameters to form the colored 3D mapping of the environment and construct a processing pipeline consisting of plane fitting and surface reconstruction using the segmentation results. We evaluate the proposed methods on the datasets acquired from the set of a Velodyne HDL-32E LiDAR sensor and a Ladybug3 panoramic camera. The experimental results verify the feasibility of the multi-modal data fusion for the colored 3D mapping. In addition, the simplification and visualization of the point cloud data with modeling abstract representation is also demonstrated.

Chapter 7 concludes this work and discusses the future work. In summary, we propose a novel scheme for accurate, effective and intelligent fusion of the LiDAR and camera data. The main contributions of this thesis include proposing an enhanced scanline-based method for segmentation of sparse point cloud, an automatic extrinsic calibration method based on reflectance intensity, effective incremental segmentation for large-scale point cloud as well as example applications of pedestrian detection and clean 3D mapping and surface reconstruction. There are still open challenges including extending the calibration method to be target-less, occlusion detection for better colored 3D mapping and automatic texture generation from images for realistic 3D reconstruction, which we will focus on as the future work.