Faro scanner localization using RTK sensors

Pingcong Li, Yuezhong Wang

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Abstract

Point clouds are widely utilized as a 3D mapping format for representing environments with high detail. The Faro scanner is a powerful device capable of generating dense, accurate, and colorized point clouds by integrating LiDAR and camera data. Accurate localization is essential to effectively merge point clouds and construct cohesive maps. This project aims to enhance the Faro scanner's localization capabilities by integrating an RTK sensor, utilizing processed RTK data to achieve precise and reliable positioning.

1 Introduction

Point clouds have become an indispensable tool for 3D mapping, enabling highly detailed environmental representation essential for fields such as land surveying, construction, and autonomous navigation. The Faro scanner, a leading device for point cloud generation, combines LiDAR and camera technologies to produce dense, colorized, and high-resolution data. However, while the Faro scanner excels in capturing spatial information, it currently lacks built-in localization capability, limiting its effectiveness in scenarios where precise positional alignment is required.

To address this, our project proposes to integrate a Real-Time Kinematic (RTK) GPS sensor with the Faro scanner to achieve high-precision localization for outdoor applications. RTK technology, known for its centimeter- or millimeter-level accuracy, enhances standard GPS data by providing real-time corrections from a stationary base station. The base station receives and calculates discrepancies in GPS signals, then transmits these corrections to the mobile RTK receiver, achieving significantly improved positioning accuracy.

Although RTK offers substantial accuracy improvements, this project seeks to further reduce localization errors. During operation, the Faro scanner will rotate horizontally from a fixed position, creating a circular path for the RTK sensor, which will be mounted to the side of the scanner. This setup is expected to generate a series of positional data points along a circular trajectory. By applying filtering techniques and geometric fitting algorithms to these data points, we can refine the localization output, achieving an even more accurate and reliable position for point cloud alignment. This enhanced localization method will support the creation of high-fidelity 3D maps in outdoor environments, making the integrated system suitable for advanced mapping and surveying applications requiring precise spatial data.

2 State of the Art

2.1 Pingcong

2.1.1 Three papers

1. The paper "Accurate and Resilient GPS-Only Localization With Velocity Constraints" proposed an improved GPS-only localization method using two velocity constraints based on Bayesian filtering to address ambiguity issues in state variables. These constraints help enhance the accuracy and reliability of localization, especially when assumptions in motion and observation models are violated.

2. The paper "Improving Positioning Accuracy Using GPS Pseudorange Measurements for Cooperative Vehicular Localization" proposed the weighted least squares double difference (WLS-DD) technique for intervehicle distance detection and the distributed location estimate algorithm (DLEA) for improved vehicle positioning. Field experiments and comprehensive simulations confirmed the effectiveness and superiority of these methods. The integration of WLS-DD and DLEA shows significant promise for accurate vehicle positioning without the need for traditional reference points.

3. The paper "Improved Iterative Closest Point (ICP) Point Cloud Registration Algorithm based on Matching Point Pair Quadratic Filtering" proposed an improved ICP algorithm based on matching point pair secondary filtering. By incorporating ground segmentation and point cloud filtering in the preprocessing stage, this approach effectively filters ground points and abnormal matching point pairs during the Kdtree_ICP registration process. Experimental results with outdoor ground point cloud data demonstrate that our proposed method significantly enhances computational speed and accuracy.

2.1.2 One paper in detail

Since that the result of localization is a series of points and we are going to utilize point cloud processing method on the result, it becomes an important problem that how to obtain an accurate and efficient registration. The paper "Speeding Up Iterative Closest Point Using Stochastic Gradient Descent" proposed a novel method called SGD-ICP to improve the performance of ICP algorithm with stochastic gradient descent. In standard ICP, it will start with a initial guess of the transformation. Then it will perform the transformation on the source point cloud and compared to the reference point cloud to get the updating result, usually from SVD. In this process, it will take every point in the point cloud into account, which leads to unacceptable time cost when facing a large dataset. Besides, in order to get a good result from standard ICP, it's important to fine tune the parameters according to the property of different point cloud data. In order to solve these problems, this paper proposed to complete the updating process as an optimization problem and utilize an efficient algorithm called SGD which is from machine learning. In each iteration, it will randomly choose a small number of points call a mini batch instead of the whole point cloud. Then it will perform the transformation on this mini batch and calculate the loss. The loss function in the optimization process is based on the Euclidean distance from transformed points to the reference points. To optimize this loss function, it will calculate the partial derivatives about each parameter of the transformation matrix. Then applying a learning rate, it can get a updating value to each parameter of the transformation matrix. To improve the performance, it could use an adaptive learning rate like the ADAM-SGD model. The experiment shows that SGD-ICP significantly improves the efficiency while has no quality loss. When the point cloud has bad properties such as an uneven distribution or low density, the SGD-ICP will give a much better result since it doesn't need to be fine tuned like the standard ICP.

2.1.3 One ROS package

In this project, it's easy to complete the localization with RTK sensor. But for robots, sometimes the task of localization may be challenging. Here shows a localization package from ROS called "robot_localization" which provides non-linear state estimation through sensor fusion of IMU, GPS, and odometry data. It provides an ekf_localization_node which is an implementation of an extended Kalman filter. It uses an omnidirectional motion model to project the state forward in time, and corrects that projected estimate using perceived sensor data. It also provides an ukf_localization_node which is an implementation of an unscented Kalman filter. It uses a set of carefully selected sigma points to project the state through the same motion model that is used in the EKF, and then uses those projected sigma points to recover the state estimate and covariance. This eliminates the use of Jacobian matrices and makes the filter more stable. However, it is also more computationally taxing than ekf_localization_node. It contains a node, navsat_transform_node, that transforms GPS data into a frame that is consistent with your robot's starting pose (position and orientation) in its world frame. This greatly simplifies fusion of GPS data.

2.2 Yuezhong

2.2.1 Three papers

1. The paper "A Scalable Framework for Robust Vehicle State Estimation with a Fusion of a Low-Cost IMU, the GNSS, Radar, a Camera and Lidar" proposes a robust and scalable framework for vehicle state estimation by integrating data from a variety of sensors, including a low-cost Inertial

Measurement Unit (IMU), Global Navigation Satellite System (GNSS), radar, a camera, and lidar. The framework employs an error-state extended Kalman filter (ESEKF) to fuse the data from these diverse sensors, enhancing the accuracy and robustness of vehicle state estimation under various driving conditions.The method leverages the strengths of each sensor to compensate for their individual limitations, providing a comprehensive solution for environmental perception, motion planning, and control in automated driving scenarios. The paper demonstrates the framework's effectiveness through experimental results, showing improved accuracy and robustness in dynamic driving maneuvers and different environmental conditions, compared to relying on a single type of sensor.

2. The paper "Building a Reliable and Cost-Effective RTK-GNSS Infrastructure for Precise Positioning of IoT Applications" presents a solution for creating a precise positioning system using Real-Time Kinematic Global Navigation Satellite System (RTK-GNSS) technology. The paper details the use of open-source software, RTKLIB, for processing rover and base receiver data to achieve high precision. The authors conducted experiments in diverse environments and found that the system maintained approximately 91% consistency in cm-level accuracy. They concluded that the accuracy, feasibility, and reliability of the system can be achieved with a low-cost RTK-GNSS receiver and sensor network, which has the potential to support precise positioning applications and enhance technological capabilities for IoT devices globally.

3. The paper "An Extrinsic Calibration Method between LiDAR and GNSS/INS for Autonomous Driving" introduces an efficient extrinsic calibration method for LiDAR and GNSS/INS systems in autonomous driving, which is characterized by its rapid and accurate calibration process, robustness against initial error variations, and the ability to correct for z-axis errors typically encountered in planar motion scenarios. This method stands out for its streamlined approach to improving the precision of sensor fusion, leading to enhanced autonomous vehicle navigation and localization capabilities.

2.2.2 One paper in detail

Accurate and reliable sensor calibration is critical for fusing LiDAR and inertial measurements in autonomous driving. more accurate results. Due to the lack of motion excitation in the vertical direction during planar motion, existing calibration methods often struggle to correct for the z-axis errors of extrinsic parameters. The paper "An Extrinsic Calibration Method between LiDAR and GNSS/INS for Autonomous Driving" proposes a novel three-stage extrinsic calibration method between LiDAR and GNSS/INS for autonomous driving. They use a vehicle collecting LiDAR and GNSS/INS sequence data at the intersection by walking three figure-8-shape trajectories and keeping the vehicle speed between 10 km/h and 20 km/h. Then, the GNSS/INS pose data corresponding to the LiDAR timestamp is obtained through the data processing module.

The first stage is rough calibrate. This step can quickly calibrate the extrinsic parameters between the sensors through point cloud surface features so that the extrinsic can be narrowed from a large initial error to a small error range in little time. The second stage is calibration refinement. To further enhance the effect of mapping, authors use octree-based optimization to divide the three-dimensional space into a voxel grid and use multi-frame point clouds for splicing and construction. First, they use the result of rough calibration to remove the point cloud motion distortion through the uniform speed model. Then, the initial calibration results are converted to the world coordinate system. After the point cloud is transformed into the same coordinate system, the space is divided into a voxel grid. If the calibration result is accurate, the space voxels occupied by all point clouds in the same coordinate system are the smallest. The final stage is the z-axis correction. In many cases, minor errors in the Z-axis will not affect the automatic driving function because the car is walking on the ground plane. Otherwise, some errors in the z-axis will cause misaligning in height. The paper proposes to use fiducial points to optimize the calibration of the z axis. They take K fiducial points of the whole map and project the map to the global coordinate system to build a local map. Then the nearest neighbor of each fiducial point is found on the local map for least square optimization to obtain the final corrected offset on the Z axis. By using experiments, the paper proves the three-stage can work more efficiently and accurately.

2.2.3 One ROS package

pcl_ros is a powerful ROS package that provides a direct ROS interface to the Point Cloud Library (PCL), making the processing, analysis, and visualization of 3D point cloud data convenient and efficient in a ROS environment. pcl_ros supports the acquisition of point cloud data from a variety of 3D sensors (FARO laser scanners) and can easily publish, subscribe, and save these data in a ROS system. pcl_ros supports the acquisition of point cloud data from various 3D sensors (e.g., LiDAR, RGB-D cameras, FARO laser scanners, etc.), and the publishing, subscribing, processing, and saving of such data in ROS systems. It seamlessly integrates with the PCL point cloud format through sensor_msgs/PointCloud2, allowing powerful algorithms from PCL, such as filtering, segmentation, feature extraction and alignment, to be applied in point cloud processing.pcl_ros provides several useful ROS tool nodes such as pcd_to_pointcloud and pointcloud_to_pcd to easily convert between point cloud files (e.g. .pcd files) and ROS point cloud messages for easy data logging, storage and debugging.In our project,we need to transform the data that collect by Faro scannar to .pcd files, and then deal with it.

3 System Description

3.1 Hardware

Our system is based on a integrated RTK sensor which consists of an antenna, a receiver, a mini-computer, a battery and so on. And there is a handbook to receive, record and process the localization data. The handbook is connected to the RTK sensor with bluetooth. The RTK sensor will be attached to a 3D-print component to be employed on the top Faro scanner. And the handbook will be employed on the tripot of the scanner. During working, the RTK sensor will spinning with the Faro scanner and the handbook will record the data.

3.2 Software

The localization data will be represented as a series of points. Since that the Faro scanner will stand on a static position while working, the points in the result forming a circular trajectory represents each working spot. In our algorithm, it firstly perform a coordinate transformation to convert the RTK data into a point cloud. Then it will repeatedly use the RANSAC method to detect circles. The distance threshold should be correctly configured to perform a proper fitting. Since that the mechanic structure of the hardware is determined, which means the proper fitted circle is expected with a radius in a specific range. Thus, we can filter the improper fittings according to the prior data. Finally, it will convert the point cloud of the result back into the RTK data.

4 System Evaluation

During scanning with Faro, we obtain precise positioning information. Each scan yields a point cloud map of the surrounding area. In one scenarios, by conducting multiple scans, we can stitch the individual maps into a larger, comprehensive 3D point cloud map. The accuracy and smoothness of the final cloud map serve as indicators of the project's success. We will test in various scenarios to ensure adaptability across different environments.

5 Result

5.1 Hardware

Initially, we planned to use a wired dGPS, which required addressing issues related to power supply and data transmission. However, in subsequent research, we discovered standalone dGPS devices, which shifted the challenge to how to securely mount the dGPS onto the Faro scanner so that it could rotate together with the scanner. To achieve this, we needed to meet three conditions: First, the mounting device had to be detachable to facilitate disassembly during transportation. Second, the position of the mount had to be consistent each time

Figure 1: RTK sensor

to prevent interference with our positioning algorithm. Third, the mounting device should not interfere with the operation of the Faro scanner or obstruct its field of view.

Since the Faro scanner's platform features two prominent raised stripes, we planned to use these stripes for alignment. Specifically, our mounting device would include special components that could align with a part of the stripes, ensuring that the device could be mounted in the same position each time. Additionally, to ensure the strength and stability of the device, we added a lower section and secured it with four screws. For the dGPS mounting, we designed two platforms: the first platform is the base, used for connecting and securing the dGPS base. However, to prevent shaking that might occur during rotation, we added a top platform to stabilize the dGPS receiver and prevent it from affecting the final results. The final presentation and the assembled effect are shown in the figure.

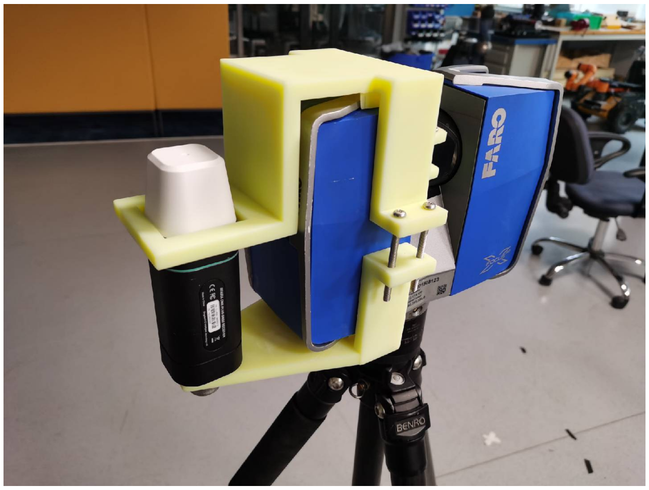

Figure 2: Carrier version 1

Figure 3: Carrier version 2

5.2 Software

Depending on the condition of the specific task, some parameters need to be configured again to improve the performance. In the test, our algorithm provided good results. Here are some example images. In the images, the blue points are the original data and red points are the centers of the circles.

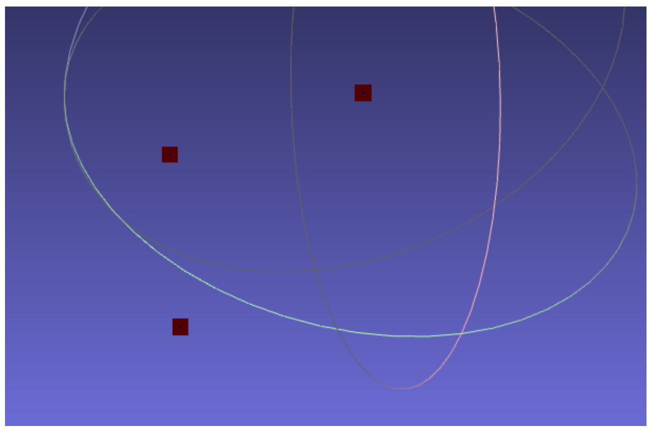

Figure 4: Result of 3 positions

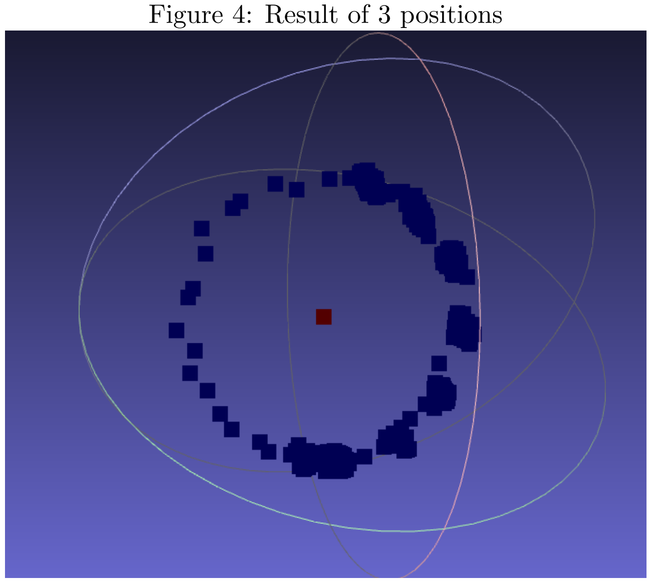

Figure 5: One of the 3 positions

6 Conclusion

In this project, we employed a RTK sensor on the Faro scanner to complete the localization task. We designed a carrier to carry the sensor. During the scanning process, the sensor will rotate with the scanner and result in a circular trajectory. We designed an algorithm using PCL to process the RTK data and calculate the position of the center of the circle to find the position of the scanner. In the experiment, we found that our first version of implementation might affect the sensor performance. Thus, we modify the structure and also the material to improve the performance. In the future, according to the requirement of the specific mission, we may have to configure several parameters or even implement more filtering algorithms to ensure the accuracy.