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Research on SLAM Method of Intelligent Vehicle Based on Lidar-IMU Combination

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Abstract. Simultaneous localization and Mapping is a key technology in the field of unmanned vehicle technology. Aiming at the present stage laser SLAM technology of gravity vector drift and elevation estimation error problem, based on the carrying of inertial measurement unit (IMU) and laser radar as experiment platform, Apollo suite with NDT method as the theoretical basis, in the Cyber RT operating system environment realize the car to the scene at the same time localization and map building. Firstly, the time stamp registration of laser and IMU is realized by calibrating the lidar. Secondly, IMU pre-integration is introduced to eliminate the motion distortion of point cloud. Then, reliable plane and edge features are obtained by feature extraction, and the depth information of environmental features is obtained. Finally, the current pose is estimated by NDT algorithm. The experimental results show that the map constructed by the combined SLAM method based on NDT algorithm has high precision and strong stability.

Keywords. Lidar, Inertial Measurement Unit, NDT, SLAM

1. Introduction

Camera and lidar are the two most frequently used sensors in intelligent vehicles, but the sensitivity of camera to illumination and viewpoint changes makes the mapping results unreliable. Lidar range measurement is accurate, data collection is not affected by environmental lighting, and the error model is clear. Its high resolution allows the fine details of the environment to be captured from a distance in a large aperture range, and it can efficiently complete the mapping task even at night. Therefore, real-time state estimation of intelligent vehicle by using 3D lidar is the focus of intelligent driving research at the present stage [1].

LIDAR-SLAM is the application of LiDAR to collect point cloud data from the surrounding environment, Based on the Iterative Closest Point[2],Correlation Scan Match[3] or Normal Distribution Transformation[4] to process point cloud data, solve the current pose, and finally output the environment map. With the maturity of lidar technology, SLAM technology turns to the practical stage. The Gmapping model[5] proposed by Giorgio, effectively solves the particle dissipation problem of particle filter, but this model is extremely dependent on external odometer. To solve this problem, Stefan[6] proposed Hector-SLAM model that does not rely on odometer data,

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but it is difficult to deal with map closed-loop. In the KITTI Open, Zhang published LOAM[7] models suitable for 3D LiDAR and extensive outdoor scenes, but lacked closed-loop detection. With the rapid development of autonomous driving technology, SLAM technology has been gradually applied, and the current research is more inclined to solve the problems existing in practical application. Google released the open source SLAM model Cartographer[8] in 2016, which mainly applied 2D LiDAR indoor SLAM estimation to effectively solve the problems of indoor localization and map reconstruction. Shan et al. proposed LEGO-LOAM [9]model based on LOAM model, which adopted ground segmentation method and point cloud clustering method to make the extracted feature points more effective. Qi Yutao [10] used the scale-invariant feature method to optimize the initial positioning problem of NDT algorithm and improve the success rate of point cloud positioning.

To sum up, the primary problem to be solved in unmanned driving is vehicle positioning. Only after the position of the vehicle is determined in the high-precision map according to the positioning information, a reasonable driving route can be planned for the unmanned vehicle, and vehicle control and attitude adjustment can be carried out according to the current position. In order to further improve the robustness of 16-line lidar equipment in outdoor road environment, this paper firstly calibrated the lidar based on Apollo development kit to complete point cloud data collection. Secondly, the motion of the initial point cloud is corrected by IMU observations. Then, feature extraction was used to obtain reliable plane and edge features. Finally, NDT optimization algorithm was used to estimate the current pose, and Apollo development kit was used for experimental verification.

2. Data processing

2.1. Coordinate system definition

According to the installation position of lidar and IMU in Apollo suite, the radar coordinate system, IMU coordinate system and vehicle coordinate system are established. Through the position relations of different coordinate systems, the coordinate conversion relations of laser points are obtained. The coordinate system position relations are shown in Figure 1.

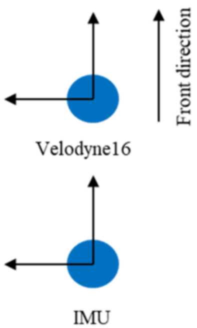
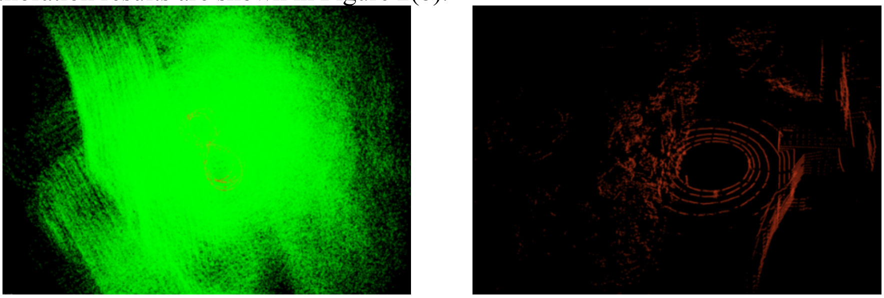


Figure 1. Sensor coordinate system position

2.2. Sensor calibration

Real-time data acquisition is carried out through fuel-client for radar calibration, and point cloud data is recorded in octagonal loop based on lidar and GNSS data, as shown in Figure 2a. After calibration, point cloud calibration data is processed by BOS, and the calibration results are shown in Figure 2(b).



(a) Point cloud calibration process (b) Point cloud calibration results

Figure 2. Lidar calibration

2.3. Point cloud information preprocessing

In this paper, the observation results of IMU are used as the initial value of lidar motion estimation to correct the point cloud [11], and the algorithm flow chart is shown in Figure 3.

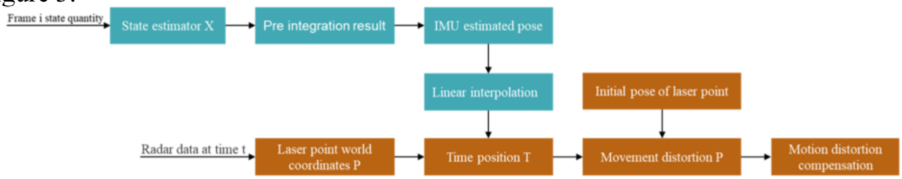


Figure 3. Point cloud motion correction

The original data ω_{j} and α_{j} of IMU can directly obtain an estimated pose through time integration, but the results of such calculation often have great observation noise. Therefore, according to the pre-integral estimation method, IMU state is defined as:

$$X_j^W = \begin{bmatrix} p_j^W & v_j^W & q_j^W & b_a^T & b_\omega^T \end{bmatrix} \tag{1}$$

The state quantity of IMU is obtained by discrete estimation of the current IMU data and the state quantity of frame i, and its expression is as follows:

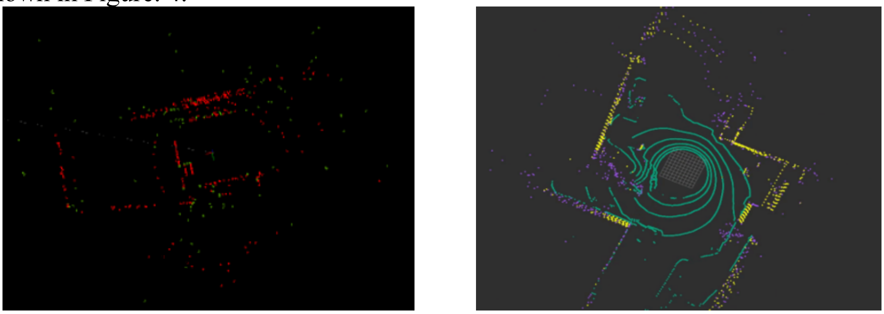
$$p_j = p_i + \sum_{k=i}^{j-1} \left[v_k \Delta t + \frac{1}{2} g^W \Delta t^2 + \frac{1}{2} R_{\mathrm{k}} \left(a_k - b_a \right) \Delta t^2 \right] \tag{2}$$

$$v_j = v_i + g^W \Delta t_{ij} + \sum_{k=1}^{j-1} R_k \left(a_k - b_a \right) \Delta t \tag{3}$$

$$q_j = q_i \otimes \coprod_{k=i}^{j-1} \delta q_k = q_i \otimes \prod_{k=i}^{j-1} \begin{bmatrix} \frac{1}{2}\Delta t(\omega_k - b_\omega) \\ 1 \end{bmatrix} \tag{4}$$

For IMU data, a linear interpolation method is adopted for Lidar data of every frame. All laser points of the current frame are converted to the Lidar coordinate system at the starting time, and the pose transformation between the current frame and the starting frame is subtracted for each laser point, so as to compensate the motion distortion caused by its own motion.

The reliability of feature points and the accuracy of feature extraction can be improved by segmenting the pre-processed point cloud. The points with the same characteristics are divided into clusters. The grounding point is a special type of cluster. Then, the clusters with points less than 40 in the cluster are removed to leave more geometric targets in the sampling points and effectively remove the influence of noise in the environment. The changes before and after point cloud information processing are shown in Figure. 4.



(a) Unprocessed point clouds (a) Point cloud after processing

Figure 4. Point cloud information processing

3. Research on Lidar-IMU combined positioning method based on NDT algorithm

3.1. Lidar -IMU optimization method

Due to the sparse ground feature points of LiDAR data, direct matching can easily lead to wrong estimation of gravity vector direction. Therefore, the algorithm adopts the joint optimization method based on LiDAR data constraint and IMU state constraint, which can effectively constrain the gravity vector direction in pose estimation. Meanwhile, LiDAR data constraint method can also eliminate the high frequency noise in IMU data. The data processing process is shown in Figure 5.

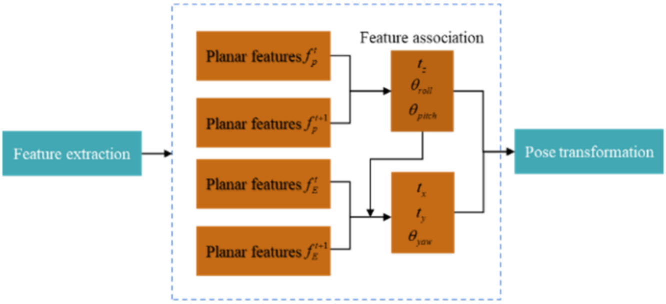


Figure 5. Combined Lidar-IMU estimate

Since LiDAR data itself does not have velocity and acceleration observation data, the target of optimization is 6-dOF pose T, then

$$T_k^L = \left(t_x, t_y, t_z, \theta_{roll}, \theta_{pitch}, \theta_{yaw}\right) = \left(p_k, q_k\right) \tag{5}$$

Where, L represents the current carrier coordinate system; p_k Represents the current location information; q_k Represents the current Angle information. Construct the joint optimization equation:

$$\min_{T_k^L} \frac{1}{2}\left\{E_L^2 + E_B^2\right\} \tag{6}$$

Finally, L-M method is adopted for iterative calculation, and the initial value of iteration T_k^L is the estimated position and attitude of the current IMU state. In this way, the number of iterations can be effectively reduced, and the wrong LiDAR feature matching caused by the assumption of zero initial value or uniform initial value can be eliminated, which is more consistent with the real motion.

3.2. Research on COMBINED SLAM based on NDT algorithm

Based on NDT algorithm, motion pose estimation of 16-thread Velodyne Lidar and six-axis IMU was carried out. Due north direction could be obtained through GNSS, and the yaw Angle of the final output was the included Angle with due north direction. The continuous frame laser point cloud is registered by NDT, and the registration result is used as the initial value of the point cloud registration of the next frame to obtain the current pose, and then the Transform relative to the initial frame can be calculated. Finally, the point cloud of the current frame is aligned to the origin of coordinates, and down-sampling is added into the map frame by frame to complete the map construction. The overall process is shown in Figure. 6.

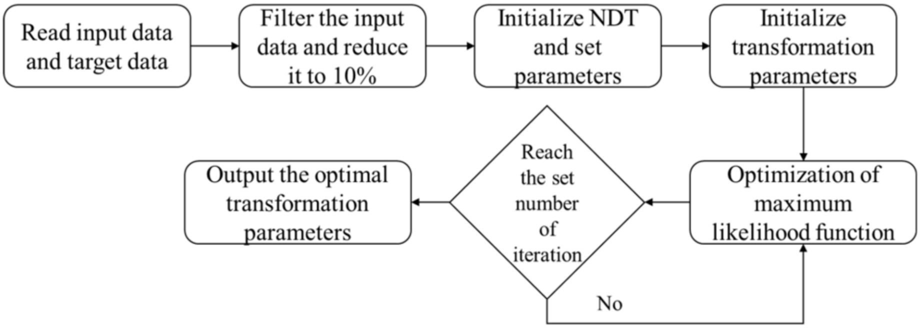


Figure 6. NDT algorithm flow

4. Lidar - IMU combined SLAM test

In order to test the accuracy and effectiveness of the algorithm, a real-time perception experiment was carried out in the closed park based on Apollo autonomous driving development kit to observe the actual driving situation of intelligent vehicles and evaluate the mapping results according to the data collected during the test.

Based on Apollo autonomous driving development kit, the real car test was carried out in the actual scene, information was collected and preprocessed for the park environment, and then the processed point cloud was registered through NDT, and finally the segmented map was obtained.

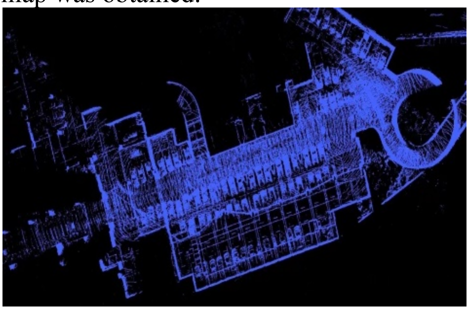


Figure 7. Results of Lidar-IMU navigation combined mapping

As can be seen from Figure 7, compared with traditional feature point method, NDT has the advantage of fast matching speed, which can be understood as uniform sampling, and can retain relatively complete details of point cloud. In structured environment with many trees, such as the scene of empty square, appropriate feature points can be quickly extracted, resulting in excellent image construction effect.

5. Conclusion

Aiming at the environment characteristics of the closed park, a laser-inertial navigation combined SLAM method for intelligent vehicle was proposed to obtain the information of the surrounding environment of intelligent vehicle. The actual scene is tested based on Apollo development suite, and the results show that the NDT algorithm has high precision and strong stability.

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