Application of Laser SLAM Technology in Backpack Indoor Mobile Measurement System

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Abstract: In the mobile measurement system, real-time acquisition of the precise pose of the carrier platform is the key to map construction. At present, the pose in outdoor mobile measurement is generally obtained by GNSS/INS combination technology. However, GNSS/INS combination technology is not suitable for the indoor scenes, and the simultaneous localization and mapping (SLAM) technology in the robot field can obtain high-precision pose by the combination of laser scanner and INS. Therefore, this paper proposes to apply laser SLAM technology to indoor mobile measurement systems. This paper designs a backpack-type mobile measurement system based on SLAM technology to measure the indoor scenes. The experimental results show that the indoor mobile measurement system combined with SLAM technology can obtain high-precision pose information and 3D integrated point cloud with indoor precision of 5-6 cm.

1. Introduction

Backpack mobile measurement system is a backpack carrier platform with integrated GPS/INS, laser scanners and other sensor device. It can measure the scene by fusing POS data and laser scan data during the movement\cite{1}. Using the INS data for dead reckoning can obtain the location and position of the carrier, but its error accumulates over time. The longer time it runs, the more severe the drift is. GNSS has high positioning accuracy, but it is greatly affected by environmental factors, especially in the environment that is blocked by high-rise buildings and street trees, and the positioning effect is relatively poor. GNSS/INS combination can achieve complementary advantages. High-precision GNSS positioning information can correct INS and limit its error accumulation. When the carrier moves in multi-occlusion environment, the high-precision position of INS can compensate for the loss of satellite signal in a short time. However, in indoor scenes, GNSS is completely ineffective due to the inability to accept satellite signals, so it is necessary to find a solution that can replace its function.

SLAM (Simultaneous Location and Mapping, SLAM) was first proposed in the field of robotics. It is used to solve the problem of acquiring the position and posture of the robot and sensing the surrounding environment in an unknown environment\cite{4}. This is consistent with the main problem in mobile measurement, namely location and positioning. The difference between mobile measurement and laser SLAM is that the former is post-processing and the latter is real-time processing. For laser SLAM, the real-time pose is solved by laser scanning matching and inertial measurement data fusion. It does not depend on satellite signals and other external sources, which can solve the problem of indoor mobile positioning and mapping.

The backpack-type mobile measurement system based on the laser SLAM combines the backpack-type mobile measurement system and SLAM technology which not only has the ability to quickly and
continuously collect data and automatically process data, but also can capture the special scene data such as indoors and underground, perfectly filling the gap of the 3D laser scanner market [2, 3, 9]. In this paper, the indoor point cloud of the 3D comprehensive measurement experimental field is collected by the backpack-type mobile measurement system based on the laser SLAM. We can obtain the high precision point cloud data and realize the construction of indoor maps by the SLAM algorithm.

2. Backpack-type mobile measurement system based on laser SLAM

2.1 Mobile measurement positioning equation

The data collected by the mobile measurement system is divided into two parts: 1) location and positioning data; 2) laser scanner raw data. The mobile measurement system can finally obtain the point cloud data with absolute coordinates by merging the pose data with the original data of the laser scanner [1]. After deriving on the basis of different coordinate system transformations, the positioning equation of the mobile measurement system laser scanner is

\[ X_e = X_{\infty} + R_e^b R_b^s R_s^e (R_e^b X_i + L_b) \] (1)

Among them, \( X_e \) and \( X_{\infty} \) are the coordinates of the data collected by the laser scanner in the WGS84 coordinate system and in the laser scanner coordinate system. \( X_{\infty} \) is space rectangular coordinates of the origin of the local horizontal coordinate system in the ECEF coordinate system. \( R_e^b \), \( R_b^s \), \( R_s^e \) respectively represent the rotation matrix of local Cartesian coordinates coordinate system to the WGS84 coordinate system, the rotation matrix of the carrier coordinate system to the local horizontal coordinate system, the rotation matrix of the laser scanner coordinate system to the carrier coordinate system, and \( L_b \) is the coordinates of the origin of the laser scanner coordinate system in the carrier coordinate system.

The mobile measurement system defines the carrier coordinate system, and the conversion parameters between the laser scanner coordinate system and the WGS84 coordinate system are solved by the carrier coordinate system. The specific process is shown in figure 1.

![Figure 1. Laser point cloud reconstruction model](image)

2.2 Backpack-type mobile measurement system based on laser SLAM

2.2.1 Overview of Backpack-type mobile measurement system

The mobile measurement system often relies on the high-precision pose information provided by GNSS/INS in an open environment such as outdoor, but the satellite signal is out of lock in an indoor environment. In this regard, the SLAM technology can be applied to the mobile measurement system and used for positioning calculation in areas such as indoors and high-rise buildings without GNSS signals, which realize the acquisition of geographic information data in various complex environments.

Leica's backpack mobile measurement system (Pegasus Backpack) is the type of device. It is a highly integrated, high-precision backpack-type mobile measurement system on the market. It has IMU and GNSS system, and has SLAM algorithm technology, which can be used indoors and outdoors to ensure the accuracy of long-time scanning point cloud and meet the task of large project measurement. The system consists of five parts: the GNSS/INS system, laser scanner, controller, power supply and tablet. By carrying a high-precision IMU, the backpack system can achieve a relative indoor accuracy of 2-3 cm (as shown in figure 2).
2.2.2 Laser SLAM Algorithm

The SLAM algorithm is mainly divided into three parts: front end, back end, and map construction. The SLAM algorithm is divided into two categories according to the different sensors: the vision-based SLAM algorithm and the laser-based SLAM algorithm. The commonly used sensors are: monocular camera, panoramic camera, depth camera (RGB-D data), 2D radar and so on \(^5,6,7\). At present, the laser SLAM algorithm gradually forms an algorithm framework with scan matching as the front end, graph optimization as the back end and loop closing. The general laser SLAM algorithm is shown in figure 3.

![Figure 3. General laser SLAM algorithm flow chart](image)

This paper takes the Cartographer SLAM algorithm as an example to introduce the key steps of the laser SLAM algorithm. The laser SLAM front end refers to the carrier POS obtained by the fusion of the IMU raw data and laser scan data. The solution of POS uses the scan matching algorithm, which estimates the inter-frame translation and rotation through two adjacent frame clouds \(^8,10\). Scanning matching mainly exists in two ideas ① based on point cloud features and ② based on all points. The idea ① refers to the extraction of features from point clouds, such as feature points, lines, vertical planes, road signs, etc. Since it is difficult to obtain stable features in different scenes in real time and there is noise in the point cloud, the idea ② is currently adopted.

During the motion of the carrier, the error is accumulated over time, and the long-term estimation result is unreliable. The laser SLAM modifies the POS by the backend optimization and loop closing algorithms to obtain a globally consistent carrier POS estimate. The specific steps of loop closing are as follows:

1. Generate the lowest resolution rotation particle;
2. Discretize the point cloud and obtain the grid coordinates of the point cloud by rounding the three-dimensional coordinates of each point;
3. Calculating particle fraction;
(4) Set the threshold of loop closing. If the rotating particle score is greater than the threshold, execute;

(5) Use the particle fraction as the new threshold, increase the raster resolution (\( \alpha - 1 \)), and perform recursively in depth-first mode (3). When the threshold is reached \( \alpha \), the rotating particle with the highest score corresponding to the highest resolution map is taken as the optimal value, and the score and the optimal value are saved.

3. Experimental design and scheme
In order to verify the accuracy and efficiency of the proposed algorithm, a data acquisition experiment was conducted at the 3D Comprehensive Measurement Experimental Field (indoor). The test was first carried out using the 3D SLAM backpack-type mobile measurement system developed by the team.

3.1 Experimental result
The data of 3D comprehensive measurement experimental field was collected. The acquisition time was 406.185s, the frequency of GX5 was 250Hz/s, and the sampling rate of horizontal and vertical VLP-16 was 20Hz/s. After modifying the source code, the number of points after processing was obtained 31142934. The overall effect of the point cloud is shown in figure 4, a) for the 3D point cloud image after processing, and b) for the top view image.

![3D point cloud and top view image](image)

Figure 4. Point cloud overall: a) 3D point cloud; b) Top view image

4. Accuracy assessment
The accuracy of the laser SLAM backpack-type mobile measurement system (3D) requires the use of markers such as spheres, cylinders and cuboids. For low-cost LiDAR, the raw point cloud has a lot of noise, so it is difficult to accurately extract the target. After extracting the target, it is necessary to design a robust scheme to evaluate the system accuracy according to the analysis of the target.

The experimental environment selects the 3D integrated measurement experiment, placing 5 balls at a certain interval and going around a circle around the room. The indoor scene and the generated point cloud are shown in figure 5 and figure 6 respectively.

![Indoor measurement scene](image)

Figure 5. Indoor measurement scene
Due to the travel route and indoor environment restrictions, the balls of No. 1, No. 3 and No. 5 are difficult to scan intact (the point cloud is distributed every circle), and the extracted sphere radius is larger than the target sphere radius. Therefore, only the point cloud of the 2nd and 4th balls is extracted (as shown in Figure 6). It can be found that there is some noise in the extraction ball and the tripod. The point cloud denoising algorithm is used to denoise and extract the corresponding ball. The top view of the extracted ball is shown in figure 7.

There are multiple balls in the extracted No. 2 and No. 4 balls. Here, the ball arc of the outermost two balls is extracted and the ball is fitted by the fit->Sphere function of Cloudcompare v2.9.1. The fitting results are shown in figure 9. The statistics of the fitting results are shown in Table 1. The spherical center distance of the 2nd fitting ball is 0.0569m, and the spherical center distance of the 4th fitting ball is 0.0589m. The indoor precision of the backpack-type mobile measurement system based on laser SLAM technology can reach 5cm-6cm.

### Table 1. Statistics of the fitting result

| Fitting the ball number | Core coordinates | Radius (m) | Fitting accuracy RMS(m) |
|------------------------|-----------------|------------|------------------------|
| No. 2 (ball 1)         | X= 0.0836 Y= 0.1660 Z= 0.0913 | 0.0761     | 0.004632               |
| No. 2 (ball 2)         | X= 0.1164 Y= 0.1093 Z= 0.0884   | 0.0762     | 0.005353               |
5. Conclusion
In this paper, the working principle of the backpack-type mobile measurement system based on laser SLAM technology and the key technology of SLAM technology are expounded in detail. The data acquisition and accuracy analysis in the 3D integrated measurement experimental field are used to verify the application feasibility of laser SLAM technology in mobile measurement system.

The mobile measurement system based on SLAM algorithm repairs and enhances POS. This technology can obtain centimeter-level measurement accuracy in indoor environment, which provides reference for research in surveying science, inertial navigation and unmanned driving. Research provides new research ideas and backpack-type mobile measurement systems will surely achieve wider application in the field of surveying and mapping.

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| No. (ball) | X  | Y  | Z  | Angle 1 | Angle 2 |
|-----------|----|----|----|---------|---------|
| 4 (ball 1) | 0.1739 | 0.1226 | 0.1405 | 0.0766 | 0.007197 |
| 2 (ball 2) | 0.1392 | 0.1701 | 0.1418 | 0.0750 | 0.009749 |