An Improved Laser SLAM Algorithm Based on Cartographer

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Abstract

SLAM is one of the core technologies in the field of robotics. At present, Laser SLAM has become the mainstream mapping solution for general mobile robots. Cartographer algorithm is one of the mainstream Laser SLAM algorithms, which has attracted much attention because of its high accuracy and suitable for large scenes. However, the effect of sensor data fusion using Unscented Kalman Filter (UKF) is not ideal. Therefore, an improved Cartographer algorithm is proposed in this paper, which uses Adaptive Unscented Kalman Filter (AUKF) to fuse information of sensors, aiming to improve the accuracy of localization and mapping.

Keywords: SLAM, Cartographer, UKF, AUKF

1. Introduction

Simultaneous Localization and Mapping (SLAM) was proposed by Smith et al. in 1986 [1]. It uses the sensors carried by the robot to complete localization and mapping in unknown environments, which provides support for subsequent autonomous navigation. SLAM can be divided into Laser SLAM and Visual SLAM according to the types of sensors it relies on. Among them, Laser SLAM has become the mainstream scheme because of its mature and stable algorithm. After years of development, there have been many excellent algorithms in the field of Laser SLAM, such as Gmapping, Hector, Karto. Among many algorithms, Cartographer algorithm has attracted a lot of attention because of its powerful function.

Cartographer is a set of Laser SLAM algorithm based on graph-optimized launched by Google, which supports both 2D and 3D lidar SLAM [2]. It can be used across platforms and supports multiple sensors such as Lidar, IMU, Odometry, GPS and Landmark. It is currently one of the most widely used Lidar SLAM algorithms in practical scenarios.

Cartographer used the Unscented Kalman Filter (UKF) to predict and fuse the information acquired by the sensors. This fusion method cannot deal with the influence of sensor noise, and will cause the decline of mapping accuracy. Therefore, this paper proposes to use Adaptive Unscented Kalman filter (AUKF) for data prediction and fusion to optimize the estimation of pose information [3].

The rest of this article is organized as follows. The second section introduces the Cartographer algorithm. In the third part, the improved method and theoretical basis are presented. In the fourth section, conduct experiments and data analysis. The fifth part summarizes the main content of this paper.

2. Cartographer algorithm

Cartographer is a state-of-the-art graph-optimized SLAM framework that was open-sourced by Google in 2016. It is designed to generate high-quality environmental maps with a high resolution of up to 5 cm, making it particularly suitable for applications requiring precise spatial understanding. The Cartographer algorithm is fundamentally divided into two key components: Local SLAM and Global SLAM, each of which plays a crucial role in constructing and refining the map.

In the Local SLAM, the submap is constructed and updated through a series of lidar scans. Odometry and IMU data were used to calculate the trajectory, and the pose of the car was estimated. The pose estimate is used as the initial value to match the lidar data and update the value of the PoseExtrapolator. In the Global SLAM, the fusion of submap is continuously updated by Ceres, and the accumulated error is eliminated by Loop Closing.

Cartographer has high engineering stability and has both mapping and relocalization. It has made innovation in improving accuracy and optimizing efficiency, and is very valuable in engineering applications.

Overall, Cartographer represents a major advancement in the field of SLAM, offering a comprehensive, reliable, and efficient solution for generating high-resolution maps and localizing in real-time. Its open-source also allows developers to adapt and extend the framework for a wide range of practical use cases, further demonstrating its value and potential in the rapidly evolving field of robotics and autonomous systems.

3. UKF and AUKF

In the Local SLAM (Simultaneous Localization and Mapping) of the Cartographer algorithm, the Unscented Kalman Filter (UKF) is employed to fuse the data from Odometry and the Inertial Measurement Unit (IMU) for precise pose estimation. However, in practical scenarios, sensor noise is unavoidable, leading to errors in the fusion process. The traditional UKF approach, while effective, may not perform optimally when the system's noise characteristics vary over time or under different operating conditions. This paper proposes an Adaptive Unscented Kalman Filter (AUKF) to improve the accuracy and robustness of the data fusion process, particularly in the presence of varying sensor noise.

The Kalman filter, a recursive and optimal algorithm, is widely used for linear state estimation. In a linear system, it provides the best estimate by minimizing the mean squared error. However, in real-world applications, many systems exhibit nonlinear behavior, which makes the traditional Kalman filter less effective. To address this limitation, various extensions of the Kalman filter have been developed, one of the most notable being the Unscented Kalman Filter (UKF).

UKF is a nonlinear Kalman filter algorithm whose main idea is to approximate the propagation and measurement model of a nonlinear function by a set of so-called "unscented transforms". This transformation works by selecting a specific set of sampling points and then calculating the mean and covariance required in the Kalman filter based on these sampling points. Compared with the traditional EKF algorithm, the UKF algorithm has better estimation accuracy and robustness, and performs better in nonlinear systems.

On the other hand, in addition to the nonlinear system model, the noise characteristics of the system may also change with time, which requires an adaptive adjustment of the Kalman filter algorithm. AUKF algorithm is an adaptive unscented Kalman filter algorithm proposed for this demand. By dynamically adjusting the parameters and noise model in the UKF algorithm, the proposed algorithm can adapt to the changes of system noise and provide more accurate and stable state estimation.

The main steps of AUKF are similar to the standard UKF, except that after each update, an adjustment step is performed to dynamically update the process noise covariance Q and the observation noise covariance R by observing the prediction error. The core idea is that if the predicted covariance is larger than the actual one, then the noise covariance needs to be reduced, and otherwise it needs to be increased. The following is a basic formula for dynamically adjusting Q and R.

$$Q_i = Q_i \times max\,(1, \frac{|P_i - P_{i_{prev}}|}{Q_i}) \tag{1}$$

$$R_i = R_i \times max(1, \frac{|y_i - \hat{y}_i|}{R_i}) \tag{2}$$

Q_i and R_i are the elements in Q and R, P_i and $P_{i_{prev}}$ are the state covariance at the current and previous step, y_i and $\hat{y}_i$ are the actual and predicted observations.

By integrating adaptive noise modeling, the AUKF enhances pose estimation reliability in SLAM applications, particularly in real-world environments where sensor noise can be both significant and unpredictable. This paper introduces the AUKF as an improvement over the traditional UKF, with the goal of boosting the accuracy and robustness of data fusion in the Cartographer SLAM algorithm and similar systems that rely on combining multiple sensor modalities, such as IMUs and Odometry.

The AUKF is employed for the data fusion and state estimation of Odometry and IMU data, playing a crucial role in combining the complementary information from these two sensors to improve overall estimation accuracy. The flowchart of position and pose estimation is shown in Fig. 1. To validate the effectiveness of the proposed method, a simulation experiment is conducted in MATLAB, where AUKF is applied to fuse Odometry and IMU data. The simulation fusion experiment of Odometry and IMU data is carried out using AUKF, and the result is shown in Fig.2.

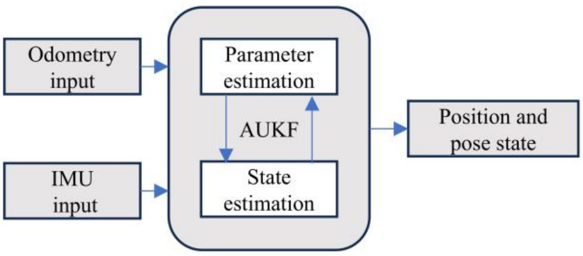

Fig. 1. Flowchart of position and pose estimation

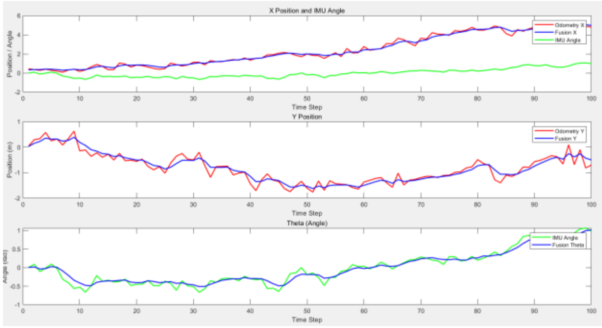

Fig. 2. Data fusion using AUKF

4. Experiment and analysis

The experimental platform used in this paper is the ROS car equipped with lidar, as shown in Fig.3. The lidar model is WHEELTEC N 10, and the system is Ubuntu18.04. N10 is a single-line lidar (Fig. 4), and its parameters and metrics are shown in Table 1.

Fig. 3. Experimental platform

Fig. 4. WHEELTEC N10

Table 1. Parameters and metrics of N10

Parameters	Metrics
Range of scan	360°
Range of measure	25m
Frequency of scan	6-12Hz
Frequency of measure	4500/s

In the indoor environment, the experimental platform was used for mapping test, the effect is shown in Fig.5. The mapping error of the algorithm is shown in Table 2. The improved Cartographer algorithm effectively reduces the absolute error and mean square error of rotational and translational. Therefore, it can be shown that the improvements in this paper can effectively transform the effect of pose estimation.

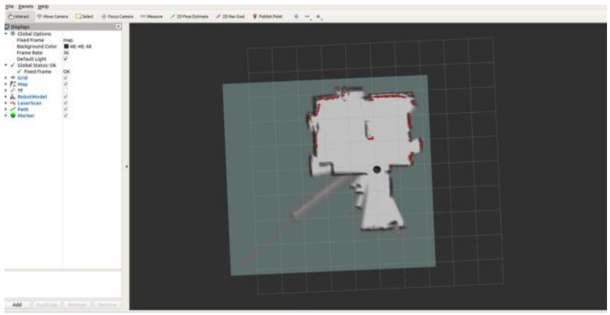
Fig. 5. Effect of mapping

Table 2. Comparison of error

Error term	Cartographer	Improved
Abs translation error/m	0.825±1.210	0.708±0.915
Rms translation error/m^2	1.246±0.587	1.023±0.372
Abs rotational error/deg	1.073±0.846	0.894±0.615
Rms rotational error/deg^2	0.957±0.657	0.785±0.493

The improved algorithm demonstrates superior performance in both the mapping quality and the numerical comparison of error when compared to the original Cartographer algorithm. Numerical comparisons between the original Cartographer algorithm and the improved version show a clear reduction in mapping errors, with the new algorithm yielding more precise and consistent maps. The error metrics, such as positioning error, trajectory deviation, and map consistency, are significantly lower in the improved algorithm, indicating that it not only performs better in real-world conditions but also offers more reliable results in terms of both localization and mapping accuracy.

In summary, the improved algorithm not only reduces the error in mapping but also enhances the overall quality and reliability of the generated maps. This improvement makes the algorithm a more viable solution for real-world applications where accuracy, robustness, and efficiency are critical.

5. Conclusion

To solve the problem of inaccurate data fusion in Cartographer algorithm, an improved Cartographer algorithm is proposed in this paper. The main focus of this improvement is to enhance the fusion of IMU and Odometry data by replacing the traditional Unscented Kalman Filter (UKF) with the Adaptive Unscented Kalman Filter (AUKF). The AUKF algorithm, on the other hand, offers an adaptive mechanism to dynamically adjust the filter's parameters based on the varying noise characteristics of the sensor data. This adaptability allows the AUKF to reduce the impact of noise, resulting in more accurate and reliable pose estimates. The experimental results demonstrate that the improved Cartographer algorithm, which incorporates the AUKF, produces significantly smaller errors in pose estimation compared to the original algorithm using UKF. Moreover, the improvements are particularly noticeable in indoor environments, where sensor noise and errors in Odometry can be more pronounced. The enhanced algorithm exhibits superior accuracy and stability, making it more suitable for real-time applications that require high-precision mapping and localization.

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