A Implementation Method of Indoor SLAM Using Velodyne Laser Radar for Mobile Robot
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Abstract. SLAM is widely studied in complex indoor environment reconstruction by mobile robot. The Rao-Blackwellised particle filter based SLAM is used for map construction and the localization of robot. It bases on the scanning data of the velodyne laser radar to perceive the external environment. And the odometer is to provide the status of robot. However, the cumulative error is produced by the odometer during the moving period. In this paper, in order to increase the accuracy of robot motion estimation, the location of the robot is updated by incorporating scanning matching. The localization and map construction of the mobile robot are achieved in indoor environment.

Introduction
With the rapid development of information technology, the indoor environment construction based on laser radar has made a breakthrough development. At present, the reconstruction technology has been applied industry and other fields, which has gradually become the research focus on mobile robot[1]. When the prospects for the development of mobile robots are promising, many key technologies and restrictive factors which are needed to be overcome have also aroused the attention of researchers.

Currently, SLAM technology is the focus of research on robot. It is the foundation of robot obstacle avoidance, autonomous navigation, path planning and intelligent implementation of other tasks. It is the key technology support for robot[2]. The research based on SLAM has attracted more attention and made some achievements. Particle filtering is a Monte Carlo sampling method based on Bayesian estimation. Its posterior probability density distribution is approximated by a set of particle sets that characterize path of robot. It mainly samples by importance functions and calculates weights of these particles. The importance weight of the particle set is obtained. We can apply the particle filter to the SLAM problem. Rao-Blackwellised particle filters (RBPF) are widely used to solve SLAM [3]. And it divides SLAM into the robot's localization and environment estimation. Rao-Blackwellised particle filter has the advantage of small amount of computation. During positioning and map building, the robot needs to obtain its own precise pose information and observed environment information[4]. The environment is constructed based on sensor information obtained by sonar, laser, vision. And laser sensor has the advantages of high precision. The measured data can be provided directly to the robot. With mature technology and gradually reduced price of laser, it has become a widely used range finding sensor[5,6].

In this paper, we use improved Rao-Blackwellised particle filter to achieve the localization and map construction of the mobile robot. The laser radar and odometer is respectively used to obtain environment information and robot's status information. And if the path of robot is estimated only by traditional odometer model, it will be difficult to position accurately for robot. So we propose a scanning matching method to increase the localization accuracy.

Implementation of RBPF
When a robot equipped with a Laser sensor (Velodyne VLP-16) perceives a scene, the conversion of global coordinates is necessary. Robot position is estimated by Rao-Blackwellized particle filter. Each particle in the particle filter represents a possible moving path, and observation information is used for particle weight calculation to evaluate each path.
**The Principle of Velodyne Laser Radar**

Velodyne's principle is that the laser transmitters a pulsed beam. The laser beam returns from the target object and will be accepted by the laser. The distance is obtained by calculating the interval between the emitted and the accepted laser beam. VLP-16 (Velodyne laser radar PUCK) is a 3D laser sensor with 16 channels. the vertical FOV of the laser sensor is +/−15 degrees and the angular resolution is 2deg, as is shown Figure 1. The range is 0-360deg in the horizontal direction, and the angular resolution is 0.2deg, as is shown Figure 2.

![Figure 1. Laser radar vertical angle change.](image1)
![Figure 2. Laser radar horizontal angle change.](image2)

**Global Coordinate Conversion**

Considering the local coordinate of the robot and the laser radar, so the observed objects need to be mapped into the map's global coordinate system in the environment. The robot pose is represented as $(x, y, \theta)$, $\theta$ is the heading of robot, $\theta_{sens}$ is the angle of the laser relative to robot. $(x_R, y_R)$ is the coordinate of robot. $L$ is the observed object by laser radar. $(x_L, y_L)$ is the coordinate of observed object. $z$ is the data of observed object by laser radar[7]. The equation for this coordinate transformation is shown as equation 1.

$$
\begin{bmatrix}
  x_L \\
  y_L
\end{bmatrix}
= \begin{bmatrix}
  x_R \\
  y_R
\end{bmatrix}
+ \begin{bmatrix}
  \cos \theta & -\sin \theta \\
  \sin \theta & \cos \theta
\end{bmatrix}
\begin{bmatrix}
  x_{sens} \\
  y_{sens}
\end{bmatrix}
+ z_L
\begin{bmatrix}
  \cos(\theta + \theta_{sens}) \\
  \sin(\theta + \theta_{sens})
\end{bmatrix}
$$

**Motion Model of Robot**

The odometer is used to perceive the robot's movement status and pose. When the robot moves, the pose of robot is represented as $s_i = (x_i, y_i, \theta_i)$ and the pose transformation is represented as $\Delta s_i = (\Delta x_i, \Delta y_i, \Delta \theta_i)$, $s_{r+1}$ is represented as equation 2.

$$
\begin{bmatrix}
  x_{r+1} \\
  y_{r+1} \\
  \theta_{r+1}
\end{bmatrix}
= \begin{bmatrix}
  x_i + \Delta x_i \cos \theta_i \\
  y_i + \Delta y_i \sin \theta_i \\
  \theta_i + \Delta \theta_i
\end{bmatrix}
$$

**RBPF Algorithm Principle**

The SLAM algorithm based on Rao-Blackwellised particle filter is to decompose the joint estimation of path and environment map into two independent parts of path estimation and environment map estimation. The map construction is decomposed into a number of independent parts, and the each map feature is estimated by the EKF[8]. The implementation of RBPF is generally divided into four steps:
Sampling: According to the initial coordinates, particle swarm composed of N particles randomly generated. The particle swarm at t time is calculated according to the motion model and particle swarm at t-1 time. Particle and particle weights are represented as equation 3:

\[
S = \{s^k, w^k\}_{k=1,...,N}, \quad s^k = (x^k, y^k, \theta^k)
\]  

(2) Computing weight of particle: Each particle is given a weight. The weight of particle is determined by the distribution function. The calculation of weight depends on the selection result of the distribution function. The distribution function usually selects the motion model. Calculating weights is represented as equation 4:

\[
w^k_{t} = \frac{p(s^k_t | z_t, u_t)}{\pi(s^k_t | z_t, u_t)}
\]  

(3) Resampling: The weight of particle is retreated as equation 5. The number of effective particles \(N_{\text{eff}}\) is calculated as equation 6 and a threshold is set. If the number of effective particles is less than the set threshold, the particle is resampling.

\[
w^{(k)}_{t} = \frac{w^k_{t}}{\sum_{k=1}^{N} w^k_{t}}
\]

\[
N_{\text{eff}} = 1 / \sum_{k=1}^{N} (w^k_{t})^2
\]  

(4) Updating map: The corresponding map for each particle based on its trajectory and observation value is calculated. The map is updated using a standard occupancy grid mapping algorithm. This algorithm bases on inverse sensor model. Whether the grid is occupied will be speculated by the measured values.

**Scan Matching Model**

As the odometer has a problem of accumulated errors, the traditional odometer model will generate large errors in the process of positioning. It will make a affect on the calculation of particle weights. Therefore, a motion model based on scan matching is proposed. Scan matching is done by matching two consecutive frames of scan data P and Q to obtain the relative transformation relationship (R,T). Based on the relative transformation relationship, the robot’s pose is obtained[9]. This will reduce the estimation error in motion.

The most widely used matching method is the ICP (iterative closest point) algorithm. ICP is a classic closest-point algorithm. It can achieve point cloud registration with high accuracy. The purpose of this algorithm is to achieve the best match between the two data set and make target function minimum[10,11,12], as is shown equation 7. After obtaining scanning information at adjacent time, the optimal transformation is calculated using ICP method, where the rotation transformation matrix is a translation vector.

\[
f(R,T) = \sum_{i=1}^{n} \|P - (RQ + T)\|^2
\]  

In this paper, in order to make the matching of the scanned data more accurate, there are two conditions for correct matching. Distance constraints and angle constraints are qualifications. When we judge similarity of angle, we use the robot as a reference. As is shown equation 8 and equation 9.
\[ \text{dist} = |\text{dist}(x_p, y_p) - \text{dist}(x_q, y_q)| \leq \delta \]  
(8)

\[ \text{deg} = |\text{deg} \varphi(P, R) - \text{deg} \varphi(Q, R)| \leq \varepsilon \]  
(9)

Experiment Results and Analysis

Analyze Radar Data

In our experiment, the laser sensor is provided with 16 channels, data1 Distance and data2 Distance is followed with 16 data (Part of the data is shown as Figure 3). The range is 0-360deg in the horizontal direction, and the angular resolution is 0.2deg. We can see from the Figure 3 that the angle between each block is 0.4deg, and the distance between data1 Distance and data2 Distance is 0.2deg. We transform the original data. Part of the data is shown. Take for example the ninth channel. The red arrow marks the distance value of the channel line, which corresponds to the formation in Figure 4.

RBPF SLAM Experiment Results and Analysis

In our experiment, a velodyne VLP-16 laser sensor are equipped on the top of robot. The robot is moving constantly in an indoor environment. In order to prove the effectiveness of the algorithm, we choose two different scenarios. And the environment results are produced by multiple experiment accumulation.

experiment one: In an ordinary and relatively simple indoor environment, the robot moves towards the wall with some angle. The experiment scenario is shown as Figure 5. The real data acquired by laser was shown in Figure 6. The constructed map by SLAM is shown in Figure 7. The experimental analysis is shown in Table 1.

experiment two: In an ordinary and relatively complex indoor environment, the robot moves parallel
to the wall. The experiment scenario is shown as Figure 8. The real data acquired by laser was shown in Figure 9. The constructed map by SLAM is shown in Figure 10. The experimental analysis is shown in Table 2.

In the experimental, we set three positions as marker points to compare the error between the estimated positions and the actual position. The estimated positions is calculated based on distance between the robot and estimated marker by SLAM. The actual position is measured between the robot and the actual marker. The distance is calculated by using coordinate of robot as a reference. The experimental results show that the error between our estimated map and the actual map is about 3cm. This error can meet our requirements.

Table 1. Analysis of Experiment one.

<table>
<thead>
<tr>
<th>Position</th>
<th>Position one</th>
<th>Position two</th>
<th>Position three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>130</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>Estimated</td>
<td>128</td>
<td>87</td>
<td>46</td>
</tr>
<tr>
<td>Cumulative</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. Analysis of Experiment two.

<table>
<thead>
<tr>
<th>Position</th>
<th>Position one</th>
<th>Position two</th>
<th>Position three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Estimated</td>
<td>98</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>Cumulative</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Conclusion

In this paper, we use the velodyne laser radar as environment sensing sensor. And scanning matching method is incorporated to obtain robot status. The improved Rao-Blackwellised particle filter algorithm to achieve the positioning of the robot and the environment construction have higher accuracy. This method has been specifically verified and applied in the reconstruction of complex indoor environments.
References


