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A loop closure improvement method of Gmapping for low cost and resolution laser scanner

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Abstract: A Kalman filter based algorithm is proposed to improve the loop closure correction performance of Gmapping using low cost and resolution laser scanners (e.g. RPLidar laser scanner), which can positively promote the application of laser scanner in normal life. Maps built up by using different cost and resolution laser scanners are compared with the conclusion that the loop closure performance of Gmapping using RPLidar is relatively bad. To solve the problem, a Kalman filter based correction algorithm is proposed to correct state estimations of Gmapping. Experiments on a TurtleBot using both RPLidar and SICK LMS laser scanners demonstrate the effectiveness of the proposed algorithm.

Keywords: loop closure, closure correction, Gmapping, Kalman filter, laser scanner.

1. INTRODUCTION

Localization and mapping are of fundamental importance in building truly autonomous mobile robots. To build an accurate map, the robot needs to localize itself precisely in the environment. At the same time, the localization accuracy depends on a carefully built map. Normally, localization and mapping happens concurrently, known as the simultaneous localization and mapping (SLAM) problem. Up to now, many SLAM algorithms have been proposed, among which extended Kalman filter (EKF), fastSLAM and Gmapping are very mature and widely used. EKF linearizes state equations around working points, then approximates the posterior probability distribution of states using Guassian distributions (Nassreddine, Abdallah, and Denoeux 2010, Genevois and Zielińska 2014). It has been successfully applied in SLAM related topics in (Choi, Choi, and Chung 2012, Teslic, Skrjanc, and Klancar 2011, Hyun etc. 2010, Moon etc. 2010). However, if the state equations are of high nonlinearity, linearization may influence estimation accuracy of EKF. Furthermore, EKF still suffers from non-Gaussian noises and the computational burden of covariance matrix (Nassreddine, Abdallah, and Denoeux 2010). On the other hand, both fastSLAM and Gmapping are particle filter based SLAM algorithms. In (Montemerlo etc. 2002), the authors decompose the SLAM problem into a robot localization problem and a collection of landmark estimation problems, which are conditioned on the robot pose estimates. The Rao-Blackwellized particle filter is applied to estimate both the posterior over robot paths and landmarks depend on the path posterior. Thus, fastSLAM still faces the problem of particle depletion and other problems such as the realization of an appropriate proposal distribution. Several solutions have been proposed in (Lulu etc. 2014, Havangi etc. 2014). Gmapping is also known as the grid map based fastSLAM algorithm. As there are no explicit landmarks, particles don't need to manage Kalman filters compared to traditional fastSLAM. But just like fastSLAM, Gmapping is built up based on the Rao-Blackwellized particle filter. So the particle impoverishment problem still exists. Giorgio etc. proposed an efficient method to solve such problem, and the experimental results show that Gmapping performs excellently with a medium number of particles even in large scale environments (Grisetti, Stachniss, and Burgard 2007, Grisetti etc. 2005). While equipped with high resolution and high frequency SICK LMS laser scanners, Gmapping also behaves well in loop closure by carefully adjusting the parameter *Neff*. But if lower resolution and frequency laser scanners (which normally is also cheaper) like RPLidar are used, loop closure is badly affected and an inconsistent map will be built up.

So here is a swing of mind: a better loop closure result with high cost laser scanner is preferred, or a lower cost laser scanner with improvements of the poor loop closure performance by using other methods is a better choice? Generally speaking, the high price of a laser scanner prevents its large-scale application. While a medium or lower price laser scanner with an acceptable resolution promotes its application, both in scientific research field and normal life. It seems that the second choice is more attractive as the resolution is guaranteed while the price of the laser scanner is much lower.

In this paper, we focus on providing a Kalman filter based technique to improve the loop closure performance of Gmapping using a lower price and resolution laser scanner.

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We first introduce the basic principle of Gmapping. Different scenario maps built up by Gmapping with laser scanner of different prices and resolutions are provided and compared, showing the necessity of loop closure improvement of Gmapping while using lower costs and resolution laser scanners. Then, the Kalman filter based technique is introduced followed with experiments and conclusions.

2. RELATED WORK

Successful loop closure is critical in building consistent map as it usually helpful in recovering the SLAM system from crash caused by either noises in measurements or fragility of the system. It can be regarded as a sub-problem of data association in SLAM, where 'data' normally refer to laser or camera measurements. The most important stage of loop closure lies in detecting the loop. (Williams etc. 2009) divide existing detection methods using visual signal into three categories: (1) *map to map*; (2) *image to image*; and (3) *image to map*, according to where the association data are taken from. Related works like (Ho and Newman 2007) adopt a matrix to code the similarity between all the possible pairs in captured images. (Angeli etc. 2008) combine the Bayessian filtering technology and the incremental BoVW together to detect loop closures, in which the probability to belong to a visited scene is computed for each acquired image. (Mei etc. 2011) represent the world by integrating advantages of topological and metrical maps, which simplifies data association and improves the performance of recognition based on appearance. Cameras can provide rich information, which are both the advantage and the disadvantage as plentiful time and resources have to be consumed (Fuentes-Pacheco, Ruiz-Ascencio, and Rendón-Mancha 2015, Boal, Sánchez-Miralles, and Arranz 2014). Laser scanner is another choice used to fulfil loop closure. Gmapping (Grisetti, Stachniss, and Burgard 2007, Grisetti etc. 2005) and Fastslam (Thrun etc. 2004) are the most popular methods. But the resolution and scanning frequency of laser scanner have to be pretty high, otherwise loop detection could be failed.

3. PROBLEM DESCRIPTIONS

In Gmapping algorithm, the grid map is used to represent an environment and the Rao-Blackwellized particle filter is employed as the state estimation technique. The key idea of the Rao-Blackwellized particle filter is to estimate a posterior $p\left(x_{1:t} \mid z_{1:t}, u_{0:t}\right)$ about potential trajectories $x_{1:t}$ of the robot given its observations $u_{0:t}$, and use this posterior to compute a posterior over maps and trajectories:

$$p\left(x_{1:t}, m \mid z_{1:t}, u_{0:t}\right) = p\left(m \mid x_{1:t}, z_{1:t}\right) p\left(x_{1:t} \mid z_{1:t}, u_{0:t}\right). \quad (1)$$

As $p\left(m \mid x_{1:t}, z_{1:t}\right)$ can be analytically (Moravec 1988) computed given the knowledge of $x_{1:t}$ and $z_{1:t}$, computing of $p\left(x_{1:t}, m \mid z_{1:t}, u_{0:t}\right)$ can be efficiently done.

According to (Grisetti, Stachniss, and Burgard 2007, Grisetti etc. 2005), the main research topics of Gmapping lie in computing better proposal distribution and reducing the particle impoverishment problem. In (Montemerlo etc. 2002, Grisetti, Stachniss, and Burgard 2007, Murphy 1999), a better proposal distribution is computed by taking the last laser scan into account. For the particle depletion problem, Giorgio etc. (Grisetti, Stachniss, and Burgard 2007, Grisetti etc. 2005) proposed an adaptive resampling method and the particle depletion problem is improved while using SICK LMS lasers even in cyclic environments.

With so many advantages, we have implemented Gmapping with source code downloaded from an open source website openslam (http://www.openslam.org/) on a TurtleBot mobile robot. Two kinds of laser scanners are used: one SICK LMS laser scanner with a pretty high price and resolution and a lower cost and frequency laser scanner PRLidar with an acceptable resolution of $\pm 0.2cm$. We find out that Gmapping performs very well in large scale indoor environment with loop closure requirements while using the SICK LMS laser scanner, but if we use RPLidar, the performance of Gmapping is drastically decreased. Fig. 1 and Fig. 2 show the maps built with Gmapping using different laser scanners. As the performance of Gmapping using PRLidar for large scale environment is quite bad, we only use it to build part of the environment map, which corresponds to the map in the red circle in Fig. 1 built up by using SICK LMS.

So our problem is: how can we improve the map with loop closure requirement by using RPLidar (or other lower cost, frequency and resolution laser scanners)?

4. THE KALMAN FILTER BASED LOOP CLOSURE CORRECTION ALGORITHM

4.1 Basic concepts

There are basically two parts included in the loop closure problem: loop detection and closure correction. Loop detection includes data association etc., and it is still an open problem to be solved. The closure correction problem is more like an optimization problem as described in (Kummerle etc. 2011), with the prerequisite of the success of loop detection which is not thoroughly solved yet.

While building maps shown in Fig. 1 and Fig. 2, the Gmapping algorithm registers laser scans if the robot moves a certain distance or the direction of the robot changes significantly, or a certain amount of time elapses, which is not easy to control. In our work, we register laser scans only if the robot moves a certain distance like around Δ meters. Let's suppose that the start gesture of the robot is $p_0\left(x_0, y_0, \theta_0\right)$, when the robot returns to the start position, k gestures are marked and therefore form the state vector $\mathbf{x}_k = \left\{x_0, y_0, \theta_0, \ldots, x_k, y_k, \theta_k\right\} = \left\{p_0, \ldots, p_k\right\}$. From the moment the robot revisits the place that is visited before, the loop closure procedure launches. In this paper, we focus on using Kalman filter to compensate the loop closure performance of Gmapping. So we make the assumption that the robot possesses the ability to accomplish loop detection.