실내 환경에 개선된 ICP 기반에 레이저 스캔 매칭 알고리즘

Laser Scan Matching using Robust ICP algorithm in Indoor Environments

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Abstract The Iterative Closest Point algorithm is a widely used approach for matching two consecutive 2 dimension laser scans which are obtained from a laser sensor installed on a mobile robot. The matching quality heavily depends on how pairs of corresponding points are established. In this paper, a robust version of ICP algorithm is proposed to increase the performance under the existence of poor initial alignment and large sensor error. Experiment results illustrate a great improvement comparing with the conventional ICP.

Keywords ICP; SLAM; Incremental Registration; Key Scan Matching;

1. Introduction

SLAM (Simultaneous Localization and Mapping) is a technique used by a mobile robot to build a map within an unknown environment and at the same time compute its current location. Our research is based on matching two consecutive 2D range scans which are obtained from a LRF (Laser Range Finder) mounted on a mobile robot.

The most widely used algorithm for matching range scans is the Iterative Closest Points (ICP) algorithm. After the ICP algorithm was originally proposed by Besl and McKay [1], many variants have been introduced based on the basic concept of ICP. Rodriguez-Losada and Minguez presented a technique to improve the data association [2]. This method is based on a distance-filter constructed on the basis of an analysis of the set of solutions produced by the associations in the sensor configuration space. Holz and Behnke proposed an efficient combination of different methods for SLAM in dynamic environments to increase the performance of ICP and reduce the probability of being trapped into a bad local minimum [3]. Pomerleau et al. proposed an adaptive rejection technique called Relative Motion Threshold [4]. The rejection threshold is calculated with a simulated annealing ratio based on paired points instead of the Euclidean distance between those points.

Since the ICP algorithm is a non-linear optimization method, it can fall into a local minimum due to outliers, occlusions and poor initial alignment. In this paper, we propose a robust ICP algorithm utilizing the point-to-line metric to speed up the convergence [5]. Incremental registration is adopted to produce a reasonable initial estimation. Moreover, a key scan matching scheme is presented to decrease the accumulated errors during a long sequence of laser scans.

2. Robust ICP Algorithm

Assume that two partially overlapping laser scans are given: the *data set* with N_p points, $P = \{ p_i , i = 1,\ldots, N_P \}$, and the *model set* with N_m points, $M = \{ m_j , j = 1,\ldots, N_M \}$. The ICP algorithm computes the rigid-body transformation based on an iterative process of two steps: first, a set of corresponding point-pairs between P and M is selected; second, the error between these corresponding point-pairs is minimized. The error function of the conventional point-to-point ICP is defined as:

$$T = (R,t) = \arg\min_{(R,t)} \left\{ \sum_{i=1}^{N_p} \left\| m_j - Rp_i - t \right\|^2 \right\}, \qquad (1)$$

where m_j and p_i is defined as the corresponding point-pair.

2.1 Point-to-Line Error Metric

The most critical part of the ICP algorithm is the establishment of correspondences. For any point p_i in the *data set P*, the conventional ICP finds the closest point in M as its correspondence, as illustrated in Figure 1(a). While the closest point criterion has the advantage of intuitive explanation and easy implementation, it suffers from sensor noise, slow convergence and large initial error. Weighted point-to-line is utilized in this paper to increase the performance of the conventional ICP. Equation (1) is modified as the following equation:

$$T = (R,t) = \arg\min_{(R,t)} \left\{ \sum_{i=1}^{N_p} \hat{n}_j \left\| m_j - Rp_i - t \right\|^2 \right\}. \qquad (2)$$

The point-to-line metric minimizes the Euclidean distance between p_i and the tangent line through m_j, which greatly increase the robustness of the ICP algorithm against sensor noises and speed up the convergence, as shown in Figure 1(b) The details of equations are illustrated in [5].

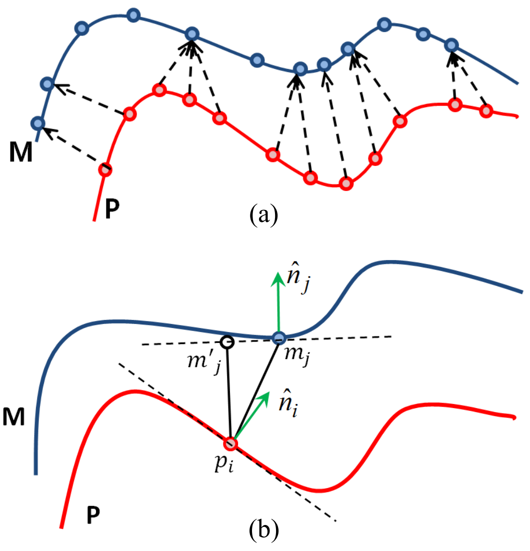

Figure 1. (a) Conventional ICP with point-to-point metric. (b) Point-to-line metric.

2.2 Incremental Registration

The local coordinate frame of the first laser scan is considered as the global coordinate frame for overall laser scans. All subsequent laser scans are registered within the global coordinate frame. In the incremental registration procedure, the last transformation result is used as the initial estimation for the current laser scan. Assume that T_{i-1} is the global transformation matrix of the laser scan S_{i-1} obtained at time (*i-1*). We use T_{i-1} as the initial estimation of the global transformation of the laser scan S_i obtained at time *i*, i.e. $T_i = T_{i-1}$ initially, and then ICP algorithm is applied to S_i and S_{i-1} to refine T_i.

The incremental registration provides a reasonable initial estimation of global transformation, and drastically reduces the probability of converging to a bad local minimum. When the wheel odometry information is not accurate, the incremental registration is an reliable alternative approach.

2.3 Key Scan Matching

The location of a mobile robot is estimated by accumulating motions between consecutive laser scans. However, small errors also accumulate in a long sequence of laser scans. The quality of localization and mapping is degraded, which leads to inconsistent scenes and robot trajectories.

In order to reduce the accumulated errors, key scan matching is adopted in this paper. Key scans are selected uniformly, i.e. one scan in every N_K scans within the input sequence. At time *i*, S_i is selected as a key scan, which is registered to the last key scan S_{i-N_K} and the previous scan S_{i-1}, obtaining two transformations $T_i^{'}$ and T_i respectively. The average transformation of $T_i^{'}$ and T_i is computed and applied to S_i. $T_i^{'}$ and T_i should be similar given a small N_K, i.e. 5 to 10. However, if the difference between two transformation matrices is very large, one of these two transformations is trapped into a bad local minimum. In this case, only T_i is applied since the overlapping area between S_i and S_{i-1} is theoretically larger than the one between S_i and S_{i-N_K}.

The scheme for key scan matching proposed in this paper is simple yet effective. The accumulated errors are spread to the whole set of laser scans, and the additional computational cost of the key scan matching is maintained at the same level as the pair-wise scan matching.

3. Experimental Resutls

The laser scans used in experiments were obtained from a Hokuyo UTM-30LX laser range finder mounted on a mobile robot. Experiments were done off-line on a PC with Intel core i5 2.66GHz CPU, 4 GB main memory and Window 7 OS. We tested the performance of the proposed ICP algorithm along with key scan matching. The global coordinate frame is identical with the local coordinate frame of the first scan, as explained in Section *2.2*. Uniform sampling is preferred in this paper because of the simplicity. The robot travelled in an indoor environment for over 50 meters while 3700 laser scans were obtained.

As shown in Figure 2(a), the experiment of SLAM was conducted using the proposed ICP algorithm. However, key scan matching was not applied, which led to the inconsistent map caused by accumulated errors. In contrast, key scan matching was adopted in SLAM as shown in Figure 2(b). Accumulated errors were reduced considerably, and the global map was much more consistent with the real world.

4. Conclusions

In this paper, a robust version of the ICP algorithm is proposed for SLAM. Point-to-line error metric is applied to speed up the convergence and reduce the impact of sensor noise. Incremental registration is utilized to increase the robustness against poor initial estimation. We

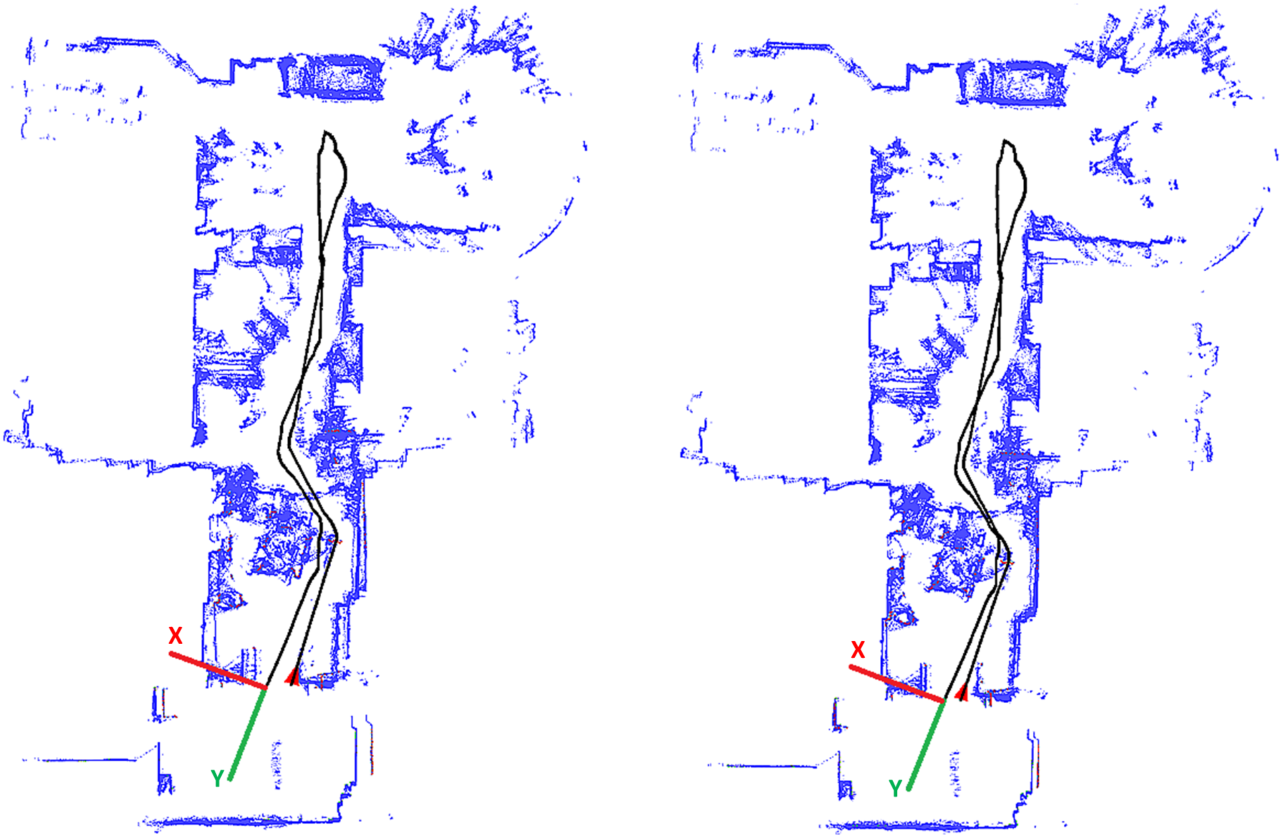

Figure 2. The 2D SLAM result for an indoor environment. The blue region is the map, and the black line is the robot's trajectory. The experiments are conducted using the proposed robust ICP algorithm (a) without key scan matching and (b) with key scan matching.

also presented a key scan matching scheme to decrease the accumulated error to increase the quality of localization and mapping. Experiments show that the results of SLAM are improved considerably. The future work includes loop closure and efficient global matching.

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