Slope Detection and Straight Line Segments based EKF SLAM

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Introduction

It is envisioned that in the near future mobile robots will be assisting human beings in their daily lives. Such robots are designed and developed to be intelligent enough to operate and share the same workplace with ordinary people. In such situation, robots are expected to be intelligent enough to move autonomously, quickly and safely without human’s control, in another word, fully autonomous navigation.

In order to realize the autonomous navigation, the robot needs to acquire the model of the surroundings and estimate the own pose with respect to the environment. This problem is well known as Simultaneous Localization and Mapping problem, which is commonly abbreviated as SLAM problem, has been investigated by many researchers since it is a basic requirement for realizing effective autonomous robotic navigation and operation. SLAM problems arise when the robot does not have access to a map of the environment, nor does it have access to its own poses. Instead, all it is given are the sensors measurements and control inputs. The goal of the SLAM problem is to reconstruct the map of the environment and estimate the pose of the robot simultaneously.

SLAM problem is the problem of spatial exploration, and it could be described as a Chicken and Egg problem. It would be a simple problem to localize the robot if the true map of the environment were available. Similarly, if the pose of the robot is given, constructing the map of the environment would be an easy job. However, it becomes extremely difficult when the localization and mapping are implemented simultaneously.

Feature based maps are widely adopted in various SLAM research works for its compactness. The drawback of the feature based maps is that it suits to the structured environment only. In this thesis, we consider line segment based representation because it requires very little memory and numerous line segments exist in a typical indoor environment when we use the laser range finder (LRF) to scan the environment.

Straight Line Extraction

This part of the thesis introduces the background of the line extraction algorithms. Based on the conclusion drew by former researchers, the algorithm called “Split and Merge” has been selected in this research work for its high speed and good correctness. The rest of this part detailed the split procedure, line fitting methods and merge method. Finally, some experimental results have been shown in this part.

Split procedure:

Split procedure can be treated as a kind of data-preprocessing which splits the whole points into several collinear points’ clusters. It consists of adaptive breakpoint detector (ABD) and iterative end point fitting (IEPF).

ABD is a point distance based segmentation method that separates the raw points into points’ clusters by checking the Euclidean distance between two consecutive points.

IEPF is a well-known recursive algorithm for line extraction. It seeks the maximum distance between the points and the line that links the two end points. The cluster will be split into two subsets if the maximum distance is oversize. This procedure is iterated to each subset until no new subsets can be found.

After the Split procedure, the raw data points scanned by LRF have been segmented as several collinear points’ cluster. Then we wipe segments that have points less than a Least Points Threshold, which can efficiently remove the noisy points. After that, we use line fitting methods to fit the straight line segments from this collinear points cluster.

Line Fitting Methods:

Two line fitting methods, Orthogonal Least-Squares Method (OLSM) and End Points Mean (EPM) has been introduced in this thesis. Each method has its own advantages and disadvantages.

The parameters of lines calculated by OLSM are relatively accurate. However, OLSM demands high computational cost for it taking every point into consideration.

The method called EPM is really fast no matter how many points existed in a single segment. And it is also accurate enough as long as the split procedure works properly.

Merge procedure:

The merging procedure allows compression and simplification of large maps without sacrificing the precision or the knowledge of map uncertainty which we gained from our line fitting algorithm.

Merging across multiple data sets is a natural extension. The basic approach is simple. First, we compare the lines and determine whether they are similar enough to merge using a chi-squared test. Then we use a maximum likelihood approach to determine the best estimate of the line pairs to be merged.
**Experiment:**

![Figure 1. The experiment of the straight line extraction algorithm](image)

Figure 1 shows the experimental result achieved by the Split and Merge algorithm. (a) the raw points for the algorithm verification was scanned by LRF URG-04LX; (b) the raw points have been split into 9 collinear points’ clusters; (c) final lines extracted by OLSM; (d) final lines extracted by EPM.

**Slope Detection**

Although researchers have done great efforts on the SLAM topic for indoor environment, most researchers assume that a robot is moving on a flat and continuous road. However, in some buildings, even in the same floor, there are some steps because of the height variation between different areas. Traditional two-dimensional (2D) mapping algorithms are not capable to detect the slope and estimate its essential parameters while three-dimensional (3D) mapping algorithms usually require much higher computational cost and memory requirement since they have to gather and deal with much more data.

This thesis presents a method to detect slope by using 2D laser range finder for robot navigation tasks in indoor environment.

![Figure 2. Basic idea of a slope detection method](image)

Figure 2 shows the basic idea of the algorithm how to detect the slope: Assuming there is a robot that equipped with two LRFs stands in front of the slope. LRF1 is mounted on the bottom platform of the robot and is used for horizontal scan. On the other hand, LRF2 is fixed on a swing mechanism driven by a stepping motor for obtaining vertical scan in required orientation with respect to the robot. For the slopes in the structured indoor environment, in most cases, the edges of the corridors and slopes are vertical to the walls on both sides while the walls are parallel or orthogonal to each other. After executing the horizontal scan by using LRF1, the robot can estimate the orientation with respect to these orthogonal walls, which means the orientation of the robot with respect to the slope, could be indirectly estimated. After that, the LRF2 implements the vertical scans in different orientations, when it successfully scanned the slope, the intersecting line (line AB in Figure 2) of the slope and the scanning plane could be extracted without difficulty. Since we already estimated the orientation of the robot with respect to the slope, the intersecting line could be divided into two orthogonal lines, line BC and line AC, which contains the information of the width, gradient and the location of the slope.

![Figure 3. Experimental environment and result](image)

**Experiment:**

![Figure 3. Experimental environment and result](image)
In the experiment, the robot executed two vertical scans as shown in Figure 3. These two scans both included the slope so that the scanned area of slope is well detected.

**EKF SLAM**

EKF-SLAM algorithm, which utilizes the Extended Kalman filter (EKF) to SLAM using the maximum likelihood data association, might be the most influential SLAM algorithm. For the past decade, the EKF SLAM has been the de facto method for SLAM. Typically, EKF-SLAM is feature based. For example, the points based EKF SLAM algorithm, which has been well investigated and detailed by researchers. However, comparing with the points based EKF-SLAM, straight line segments based EKF-SLAM is more intuitive and compact during the real application in the indoor environment.

In EKF-SLAM, the map is represented as a large state vector stacking robot pose state and landmarks state, and it is modeled by a Gaussian variable. This map is maintained by the EKF through the processes of prediction (the robot moves) and correction (the robot observes the landmarks in the environment that had been previously mapped).

Table 1 matches the relationship between the robot navigation event and EKF-SLAM.

<table>
<thead>
<tr>
<th>Event</th>
<th>EKF-SLAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robot moves</td>
<td>State prediction</td>
</tr>
<tr>
<td>Sensor detects new landmarks</td>
<td>State augmentation</td>
</tr>
<tr>
<td>Sensor detects known landmarks</td>
<td>State correction</td>
</tr>
<tr>
<td>Mapped landmark is corrupted</td>
<td>State reduction</td>
</tr>
</tbody>
</table>

**Experiment:**

During the experiment, the robot turns left first, and then moves along a long and straight corridor.

Figure 4 shows the localization (green curve) and mapping (red lines) result based on the dead-reckoning localization method. This map is simply constructed by adding every scanned line without any merging. The error of the reckoning route is unbounded as the error accumulates with the robot movement.

Figure 5 shows the EKF-SLAM result. The EKF algorithm significantly corrects the localization result and the lines are merged well. Although the mapped corridor is not strictly straight for having some slight left shift, the mapping result is acceptable since the left shift brought by the dead-reckoning has been well corrected.

**Conclusion**

The research work in this thesis first detailed one superior line extraction method named Split and Merging line extraction. Secondly, the orthogonal assumption based slope detection method has been proposed. Finally, the popular SLAM algorithm which based on the Extended Kalman Filter has been explained. In each part, the experimental results have been presented to verify the validity of the algorithms.

The Split-and-Merging algorithm is the most popular line extraction method for its superior speed and correctness. In this study, after the split procedure, two line fitting methods, OLSM and EPM have been introduced. After the comparison by the experiment, it has been shown that the EPM performs much faster and equivalent correctness comparing with OLSM.

The proposed slope detection method is based on the orthogonal assumption which is suitable for the structured indoor environment. Since it does not need massive data as required in 3D mapping method, it is computational inexpensive. And the experimental result shows the efficiency of this method.

EKF SLAM is the most popular algorithm applied in the SLAM research work. Instead of popular points based EKF SLAM, the straight line segments were adopted as the feature since its ubiquity in the indoor environment. The experimental result show good result in spite of the high demand of the computational cost after the feature numbers increased.