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Graph-based SLAM Approach for Environments with Laser Scan Ambiguity

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Abstract - The study of UGVs (Unmanned Ground Vehicles) has been actively promoted and researched. In order to operate unmanned vehicles or robots autonomously, it is necessary to understand the surrounding environment and know where it is. This paper proposes a novel localization method using a monocular camera and a laser scanner for a robot in an environment that is difficult to localize. We exploited the hybrid method between depth data from a laser scanner and the image feature of the camera, and then the collected robot pose information is estimated using the pose graph structure. In order to verify the performance of the proposed algorithm, experiments are conducted in an indoor environment. The results of the proposed algorithm are then numerically compared with the results of the conventional method. We confirmed that it is possible to localize the robot in environments with laser scan ambiguity such as a long corridor.

Keywords - Laser scan ambiguity; Graph-based SLAM; Hybrid method.

1. Introduction

The industrial robots have a limited operating rage in a fixed position. In contrast, the mobile robots have a wide range of utilization because there is no lack of mobility. Therefore, it is important to estimate the robots location in a given mapped situation to do the tasks [1-2].

For the localization, different types of sensors like GPS, IMU, vision sensors, and laser scanners are used. The localization using the GPS (Global Positioning System) use triangulation method to calculate the robots pose from 3 satellites signals. To do the exact estimation about robot pose, the line-of-sight connections are needed between the GPS receiver and satellites. The GPS system is unfit to non-wide-open spaces and has a multipath propagation problem [3]. The ways to use the IMU (Inertial Measurement Unit) estimate the 6DoF (Degree of Freedom) robot pose from gyroscopes and accelerometers which are installed on the robot. The IMU sensor values which are velocities or accelerations are integrated to obtain the position of the robot. The IMU is extremely sensitive to measurement errors and the drift is an unavoidable problem [4]. The exteroceptive sensors like GPS and cameras are used to remove the error which is integrated over time. The vision-based localization estimates the robots pose by matching features between the ready-made map and sensor images. Vision systems are lightweight, compact, relatively inexpensive and can provide high resolution [5]. But the camera images are sensitive to scene variations like a season or environment changes. The computation cost is considerably high and good visual features are more difficult to extract and match [6]. The laser scan data based localization calculates the time of flight of the light beam extracted from the laser scanner. It is a very accurate localization method. In contrast with GPS and vision sensor, the laser scanner receives less of an effect on external environments [7].

Although the localization results using the laser scanner guarantees the accurate performance, however the conventional Simultaneous Localization And Mapping (SLAM) algorithm using the laser scanner may lead to a localization failure in environments with laser scan ambiguity such as long corridors. In this paper, we propose a novel robot localization approach to the graph-based SLAM for laser scan ambiguity environments. This approach exploits the graph-based SLAM and the proposed hybrid method. The hybrid method using the single camera and the laser scanner allows the robot to estimate the pose robustly in laser scan ambiguity.

The remainder of this paper is organized as follows. The hybrid method using the graph structure for the environments with laser scan ambiguity is presented in Section 2. In order to evaluate the performance of proposed method, conducted experimental results are described in Section 3. In Section 4, conclusions of our work and future work are presented.

2. Graph-based SLAM using Hybrid Method

In this section, we describe the robot localization approach in environments with laser scan ambiguity. First, hybrid method using a monocular camera and a laser scanner is presented. Then, graph structure for optimizing a pose results from odometry, the laser scanner, and hybrid method is introduced.

2.1 Hybrid Method

The constraints from the hybrid method are used for the graph structure. The overview of hybrid method is shown in Fig. 1. The Speeded Up Robust Features (SURF) [8] algorithm extracts the feature point from the monocular camera. In order to estimate a 3D point of feature from image data, the laser scan line is projected on the image plane using the relative pose between the monocular camera and the laser scanner. If two feature points have the same value in horizontal axis on the image plane, two feature also have the same depth value because the wall is not inclined in indoor environments. The depth value of the image feature points can be deter-

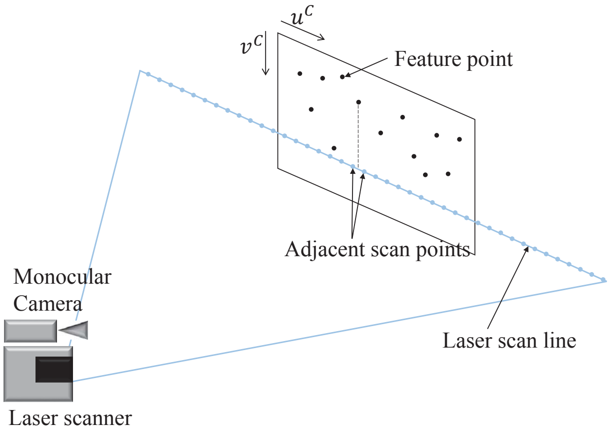

Fig. 1 Hybrid method. The 3D point of image feature can be determined using the depth value of the laser scanner.

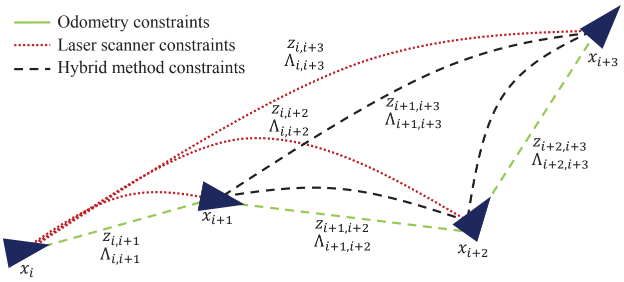

Fig. 2 Graph structure. The triangle indicates the node, the green solid line the constraints from the odometry, the red dotted line constraints from the laser scanner, and the black dashed line constraints from hybrid method.

mined from the depth data of the laser scanner. Through the linear interpolation value of the adjacent laser scan points, the depth value of the feature points is calculated. Then, the 3D point of the feature is obtained.

2.2 Graph Structure and Optimization

The pose graph structure of the proposed method is shown in Fig. 2. The graph structure is constructed with nodes (x_i) and constraints ($z_{i,i+1}$, $\lambda_{i,i+1}$). The triangle indicates the node, the green solid line constraints from odometry, the dotted red line constraints from the laser scanner [9], and the black dashed line constraints from hybrid method. The overall flow diagram is shown in Fig. 3. From the hybrid method, ground are extracted and the image feature points on the wall can be determined. The feature points enable the robot to find the revisited place in the loop closure process. In order to optimize the graph model, sparse linear algebra method [10] is used.

3. Experiments

This section presents our experiments in detail. In order to verify the performance of proposed method, the experimental environments where the experiment was conducted are provided. Then, experimental results are de-

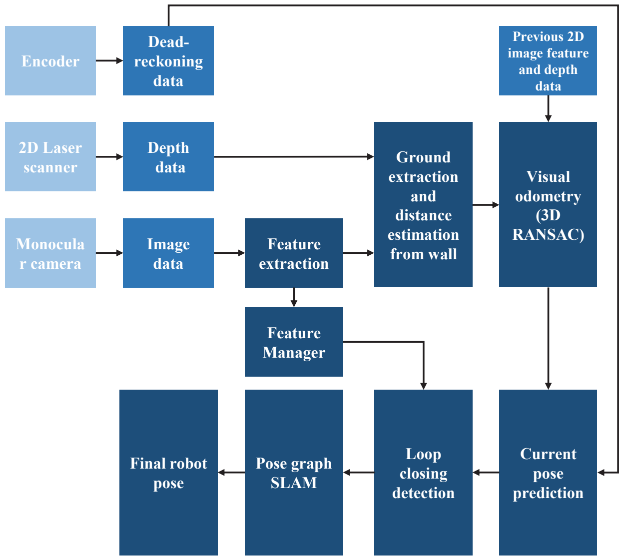

Fig. 3 Overall flow diagram of the proposed method.

scribed graphically and numerically.

3.1 Experimental Environment

The experimental environment is L-shaped long corridor which of size is 16.0m $\times$ 0.9m. The experimental environment consists of concrete wall and the featureless environments cause the laser scan ambiguity. Therefore, it is difficult to estimate the accurate robot pose using only laser scanner because data of the laser scanner are uniform. The number of the ground truth is 43. In the experiment, the robot passes through the ground truth points that manually measured in advance.

3.2 Experimental Results

The graphical experimental results are shown in Fig. 4 and Fig. 5. In Fig. 4, the grey solid line means the ground truth, the green rectangle solid line odometry, the red circle solid line the trajectory from the GMapping [9], and the black dashed line the results of proposed method. The error of odometry is larger than the others. The errors of GMapping and proposed method may look like similar. However, the error of proposed method is smaller than GMapping especially along to the X direction. The error results that the proposed method error is smaller than GMapping can be numerically evaluated in Fig. 5 and Table 1. Table 1 describes the Root Mean Square Error (RMSE). The RMSE values of proposed method are smallest in comparison with others both X and Y direction.

Table 1 RMSE results.

RMSE	X	Y
Odometry	3.7387	3.9059
GMapping	0.7164	0.1080
Proposed	0.3790	0.0792

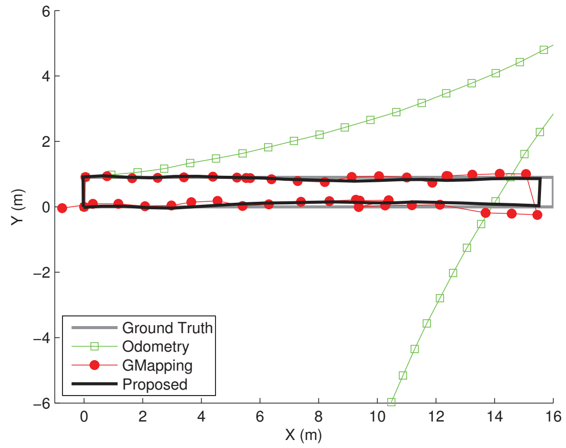

Fig. 4 Localization results. The grey solid line indicates the ground truth, the green rectangle solid line odometry, the red circle solid line GMapping, and the black dashed line proposed method.

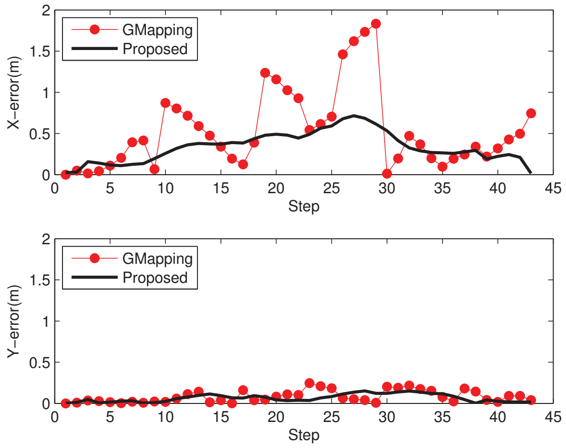

Fig. 5 Error at each step for GMapping and proposed method. The proposed method has a better performance than GMapping.

4. Conclusion

In this paper, we introduced a novel approach to localization using a graph structure-based SLAM algorithm in environments where the conventional algorithm using a laser scanner may lead to localization failure. For the robust localization results in environments with the laser scan ambiguity, we used a monocular camera and a laser scanner and proposed a hybrid method. The graph structure was used for compensating the shortcomings of each sensor. In order to evaluate the performance of the proposed method, the experiment was conducted in the long corridor environment. It was shown that the proposed method has a better performance than GMapping numerically and graphically in laser scan ambiguity. As a future work, we will extend the localization algorithm by applying a probabilistic method for outdoor environments.

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