이동 로봇의 위치 추정을 위한 초음파 링 데이터를 이용한 효과적인 환경 인식법

Effective Recognition of Environment Using Sonar Ring Data for Localization of a Mobile Robot

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1. Introduction

Autonomous navigation of a mobile robot requires some vital functions including map building, localization, path planning, obstacle avoidance, etc. In most cases, the localization of a robot pose is essential because its result has a great effect on the performance of the other functions.[1] The key in the localization is to keep the confidence of a robot path well against systematic errors, which are caused by kinematical imperfections of the mobile robot, and non-systematic errors, which may be caused by wheel-slippage or irregularities of the floor.

Various sensors such as laser scanner, vision camera, infrared scanner, and sonar sensor have been used to recognize the environment for the localization. A sonar sensor has been one of the commonly used sensors because it is cheap and gives direct depth information on the location of object. However, the specular reflection of a sonar beam gives rise to the multipath phenomenon, which, together with the wide directivity, makes it very uncertain to decide the exact locations of objects.[2] Since a single rotating sonar sensor is not feasible in practice due to the low measurement speed, the fixed-type sonar ring has been preferred. Nevertheless, localizing a robot pose by using cheap sensors such as sonar deserves to research.

Leonard and Durrant-Whyte showed two implementations of EKF localization which used a simple vehicle with a single rotating sonar sensor and a mobile robot with six static sonar transducers.[3] Stopping a vehicle to obtain sets of data takes a great deal of time even though the certainty of RCDs(Regions of Constant Depth) extracted from densely scan sampled at a single location are very high. Further more, sonar data taken by six isolated sensors are too uncertain to update the vehicle’s orientation. Wijk and Christensen presented a sensor fusion scheme, called TBF(Triangulation-based Fusion) of sonar data. The TBF algorithm, delivering stable point landmarks, is implemented as a voting scheme, which group sonar measurements that are likely to have hit a mutual object in the environment. They applied the TBF algorithm to track the robot pose.

This paper suggests the effective recognition method increasing the visibility of sparsely sampled sonar data for the localization of the mobile robot. To evaluate the robot pose effectively, two kinds of observations are defined; the scanned feature and the tentative feature. The scanned features are extracted from the group of the previous scanned data. We also adapt the data, which could not satisfy the qualification for scanned feature extraction, to the localization task as the tentative feature. The tentative features are estimated by matching the current data to the existing landmarks. Both of feature observations are applied to EKF(Extended Kalman Filter)-based localization track. We demonstrate the validity of the proposed recognition method with the results produced by real experiments.

2. Scanned Feature Extraction

We have tried to use the fixed-type sonar ring with 8 pairs of Murata sensor in the paper. Since the sonar ring gives too sparsely sampled data for a single rotating sonar sensor or a laser scanner, it is impossible to use powerful data filter like RCDs in the work.[3] It, therefore, strongly requires a kind of filter that can reject false data and gather true data. The data association (FPA, FootPrint Association) filter introduced in the previous works[4] classifies sonar data measuring the same object into one group for extracting the feature. The FPA filter basically determines whether the set of two sonar data measured at different sensor locations is originated from the same object or not.

FPA filter has the ability that classifies reliable returns from the same object into one group and also estimates the possible location of an object within the sonar edge. It’s why we can extract the scanned feature directly by using Least Square optimization, not Hough transform or RANSAC (Random Sample Consensus) of voting scheme.

3. Estimation of Tentative Feature

The robot path tracking with only scanned features from the sonar ring can give unexpected danger even though those are so precise, since the sonar ring tends to give data sparsely and the visibility of features can become lower. For this reason, we let the data, which could not satisfy the qualification for scanned feature detection, participate in the estimating process of the tentative feature.

Before estimating the tentative feature, we evaluate the reliability of current data which was measured at the robot pose and did not satisfy the qualification for the scanned feature extraction. The preliminary data filtering should be needed to distinguish reliable measurement from spurious data against the multipath phenomenon by the specular reflection of a sonar beam. This data reliability is, also, evaluated by using FPA filter according as how much acceptable the sonar data is geometrically at an object boundary. This filtering can be help to estimate the tentative features effectively, although the evaluation condition of data reliability is looser than that for the scanned features. It means that the visibility of sparsely sampled sonar data for the localization of a mobile robot can be better.

The heading angle of the robot as well as the poses of x and y axes can be compensated with the scanned features, because these give the reliable information on the direction to features from the robot. However, the high failure possibility of the robot pose recovery against the accumulated odometry error exists always due to the low extraction frequency of the scanned features. On the other hand, the tentative features can compensate only the robot poses of x and y axes except the heading angle of the robot. Nevertheless, the tentative features can help the robot pose not to be diverge with the scanned features due to the tentative features can be detected frequently. Accordingly, the robot pose confidence can be guarantee as applying the frequently detected tentative features as well as the scanned features into the localization task although the sparsely sampled data from the fixed sonar ring is used.

4. EKF Localization of Mobile Robot

Localization of a robot pose is defined as the problem of tuning the pose of a robot relative to a given map of an environment. To execute the localization successfully, observation values gained by sensor data should be obtained with precision and consistency. In this paper, two observations of the scanned feature and the tentative feature are applied to the EKF localization track. EKF localization consists of two steps; the prediction and measurement updating steps. In the prediction step, the robot pose and the covariance of the robot's pose error are predicted based on the odometry and the system parameters. In the measurement updating step, the pose and covariance of the robot are updated by using the innovations calculated from the detected features by sensor observations.

5. Experimental Results

Experiments were carried out using a Pioneer-3DX that is differential drive-type robot, and is equipped with a sonar ring composed of 8 Murata sonar sensors. The radius of the sonar ring is 16cm and the height above the ground is 37cm. The Polaroid sonar sensors mounted on the robot initially by the manufacturer were not used. The robot explored one loop with an average speed of 0.2m/s manually. During the robot's motion, the sonar ring acquired range data at frequency of 5Hz. The experimental environment of the corridor was in the engineering building at the Cheju National University. Specifically we put the circle-type baskets at several places in the corridor for verifying the detection ability of circle-type objects.

Figure 1(a) shows the drift of the odometry-based trajectory from the true path of the robot because of systematic and random errors. The robot path based on the odometry was distorted so much as shown in the figure. It also shows the reference landmarks selected for applying EKF localization, which are composed of line, point and circle features. Figure 1(b) shows the results of localization. We can know that all most scanned features extracted through sparse sonar data of a sensor ring are useful to localize the robot pose in EKF frame.

The number of updating times with the scanned features in EKF process was 37 during all robot trajectories. The total trajectory of the robot was about 30.53m. So, the average updating number is 1.21 times per meter. From sparse observation frequency of the scanned feature and unstable robot trajectory caused by EKF localization with only scanned features, it can be judged that it is hard to keep the confidence of a robot pose well with only scanned features extracted from the fixed sonar ring against the odometry error etc.

Figure 2 shows results of EKF localization with both the scanned features and the tentative features. The scanned features were drawn by a bold line like as Fig. 1(b). The numbers of updating times with the scanned feature and the tentative feature in EKF process were 37 and 196 respectively during all robot trajectories. So, the average updating number is 7.63 times per meter. In comparison with both of total corrected robot trajectories of Fig. 1(b) and 2, we can know that the error fluctuation of the updated path around the true path of a robot during using two kinds of feature observation became less than one with only the scanned feature. The error variance of a robot pose from the true pose during total trajectory under the situation of Fig. 1(b) is 9632 [mm^2] while it in Fig. 2 is 5316 [mm^2]. Additionally, we can guess that the stability of a robot pose in EKF with all feature observations is guaranteed more than it with only scanned features to get the autonomous navigation of a robot using sonar rings.

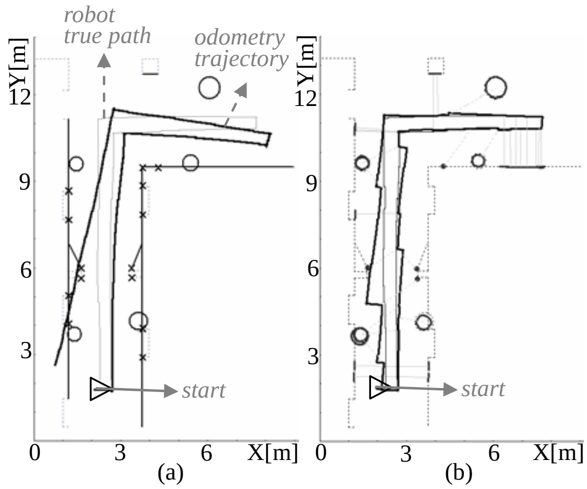

Fig. 1 (a) Selected reference landmarks and the odometry-based trajectory of the robot. (b) The results of EKF localization with only the scanned features.

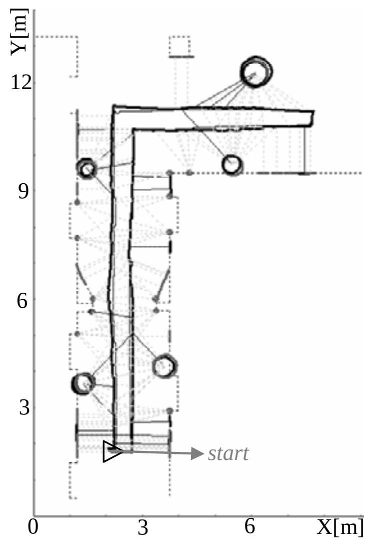

Fig. 2 The results of EKF localization with both of the scanned features and the tentative features.

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