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Effective RFID Tag Positioning Strategy for Mobile Robot with Indoor Mapping

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Abstract: To achieve accurate localization of mobile robot in indoor environment, various methods which are based on RFID technology have been developed over the past decade. Especially, the distribution of RFID tags is one of the main issues in real-world applications. In this paper, we propose a new RFID tag arrangement strategy based on the topology of the given map. The proposed method divides the given map into geometric sections by applying Voronoi graph method. To estimate accurate position in local section, we adopt the particle filter; this causes computational complexity. By modified weighting of the particle filter, we can reduce the number of particles.

Keywords: Localization, RFID, Voronoi diagram, Topological map, Mobile Robot

I. INTRODUCTION

Localization is one of major issues for the mobile robot. Usually, the measured position of a mobile robot is different from the true position and this causes serious problems to moving the robot to the desired position.

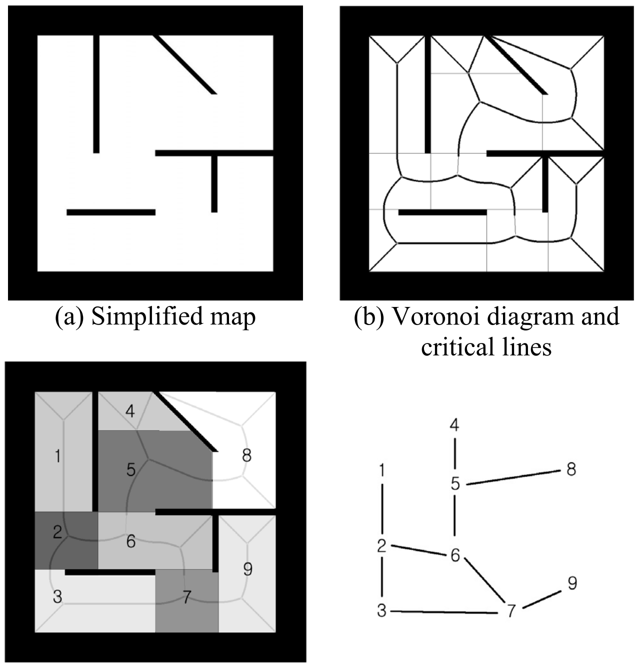
To overcome this problem, various methods are proposed. The GPS (Global Positioning System) [1] and the RFID (Radio Frequency Identification) [2] provide absolute position information. For the indoor localization, a RFID system is extensively used because the GPS is not available. An RFID system consists of readers and tags and tags can provide absolute/relative position information to the reader in a range manner.

RFID systems can be divided by the way of tag responding into two types: passive or active [2][3][4]. RFID systems also can be categorized by distribution of tags [5]. To estimate the robot position in the map, various types of tag-deploying such as grid, equilateral triangulation and random distribution have been proposed [6].

In this paper, we present a strategy that is based on the geometrical segmentation of the given map. To achieve this result, the Voronoi diagram of the map is used. When the number of RFID tags is not sufficient to make repeatable patterns, the proposed method can help localization.

To estimate more accurate position, we adopt the particle filter that uses the other information from measurement units such as odometry and laser-range-finder. Moreover, we reduce the computational burden of the particle filter by using RFID tags.

This paper is organized as follows. In section II, we will present the method of the geometrical map segmentation and modified version. Then we describe the particle filter and modified application with the RFID information in section III. In section IV, we will



(a) Simplified map (b) Voronoi diagram and critical lines

(c) Regions (d) Topological graph

Fig.1.The result of geometrical map segmentation

propose an effective RFID tag positioning strategy. Then section V gives the result of simulation. Finally, we conclude the presented research work in section VI.

II. GEOMETRICAL MAP SEGMENTATION

The method of the geometrical map segmentation was presented[7]. We use modified version of the method as follows.

1) Thresholding and simplifying

First, we take thresholding. To make all obstacles in the given map into convex polygon, small wiggled line should be corrected by some simplify because Voronoi diagram can handle convex figures only(Fig.1(a)).

2) Voronoi diagram

We achieve Voronoi diagram for all possible points and eliminate some points and lines that is out of the bound or in obstacles.

3) Critical points

Critical points are points on the Voronoi diagram that minimize clearance locally.

4) Critical lines

Critical lines are obtained by connecting each critical point with its basis points (Fig.1(b)).

5) Regions

Regions are obtained by dividing map with critical lines(Fig.1(c)).

6) Topological graph

The partitioning is mapped into an isomorphic graph(Fig.1(d)).

III. ESTIMATION WITH PARTICLE FILTER

1. Particle Filter

When we consider nonlinear system with non-gaussian error distribution, the particle filter is more effective method to estimate than classical approaches such as Kalman filter and extended Kalman filter. An implementation of the particle filter is given as follows [8][9].

Algorithm:

1) Initialization:

Generate $x_0^i \sim p_{x_0}, i = 1,...,N$. Each sample of the state vector is referred to as a particle.

2) Measurement Update: Importance weighting

Update the weights by the likelihood.

$w_t^i = w_{t-1}^i p(y_t \mid x_t^i) = w_{t-1}^i p_{e_t}(y_t - h(x_t^i))$,

where $i = 1, 2, ..., N$.

After updating, normalize $w_t^i := w_t^i / \sum_i w_t^i$.

3) Resampling

a) Bayesian Bootstrap

Choose N samples with replacing particles from the set $\{x_t^i\}_{i=1}^N$, where the probability to choose sample i is w_t^i. Let $w_t^i = 1/N$. We call this procedure as sampling importance resampling(SIR).

b) Importance Sampling

If the effective number of samples is less than a threshold N_{th}, resampling becomes

$$N_{eff} = \frac{1}{\sum_i (w_t^i)^2} < N_{th},$$

where, $1 \le N_{eff} \le N$. The upper bound is for that all particles have the same weight, and the lower bound is for that only one particle is remained. We choose the threshold as $N_{th} = 2N/3$.

4) Prediction

Simulate the system and derive the prediction

5) $t := t+1$*, iterate to 2)*

where

x_t state vector;

u_t measured inputs;

y_t measurements;

e_t measurement error;

2. Modifying Particle Filter for RFID

If the mobile robot read one or more tags, the probability of its existence near the tags greatly increases. Applying the RFID information to the particle filter can drastically reduce the number of particles which is required for localization [10].

In this paper, we adopt the modified particle filter for RFID system which can enhance the performance of the localization [11]. While processing the particle filter with the data from the sensor such as wheel-encoder or a laser-range-finder, the importance weighting step of the filter is modified with RFID information. If particles are in the range of responding tags, the likelihood of the particle will be increased (Fig. 1). The modified algorithm is given as follows.

Modified algorithm in particle filter

2) Measurement Update: importance weighting

For each particle after calculating likelihood

Loop *for each responded RFID tag*

If *(the tag matched to the particle)*

$count_m$ ++;

End If

End Loop

If *($count_m$ ==0)*

likelihood = 0;

Else

*likelihood = likelihood * $rate_w$ ^ $count_m$*

End If

where

$count_m$ matched tag count

$rate_w$ weight rate

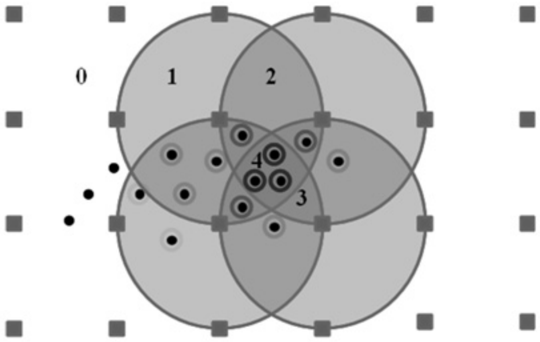


Fig.2. An example of the modified algorithm in particle filter. Each square represents a RFID tag and large circles are responding range of tags. The numbers are for matched tag count on the area and dots are for particles. The density of small circles represents assigned likelihood of each particle.

IV. RFID ARRANGEMENT

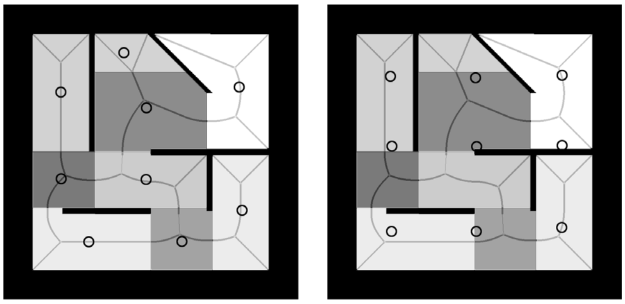
First, we define the two parameters: the number of RFID tags, N_{tag} and the number of sections in given map N_r. In the case of $N_{tag} >> N_r$, the distribution strategy is not important. Therefore we focus on the case $N_{tag} \approx N_r$. As shown in Fig.3 (b), patterned distribution does not consider the geometry of the map; some region has no RFID tags. The proposed method placed the RFID tags on the center of gravity of each region. Therefore robot meets the RFID tags once at least for a region. This prevents the error accumulation. Moreover, Voronoi diagram method generates lines which never cross the obstacles; robot in navigating has a tendency to follow the Voronoi diagram lines; a probability of the encounter between robot and RFID tags is increased when RFID tags are placed on the Voronoi diagram or near the Voronoi diagram

V. SIMULATION RESULT

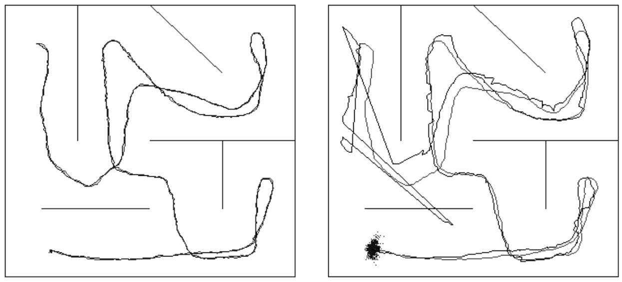
The simulations are performed by using MATLAB. In all simulations, particle filter is used to estimate the position of the robot. The measurement length of Laser-range-finder is same and measurement noise is 20dB.

Fig.4 (a) and (b) uses the particle filter and laser-range-finder but RFID tags are used only in Fig.4 (a). In Fig.4, it is shown that fewer particles are used in Fig. 4(a) because absolute position can be measured.

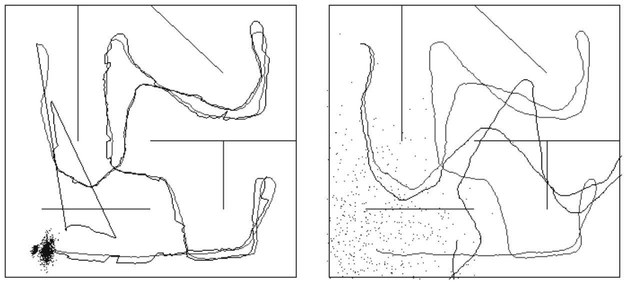
Fig. 5 shows that the auxiliary sensor information improves the performance of the localization. Two simulations used same number of particles but their trajectory is somewhat different.



(a)Proposed (b) Patterned distribution
Fig.3. RFID arrangement



(a) N = 50, with RFID and laser-range-finder (b) N = 800, with laser-range-finder only
Fig.4. Tracking error with / without RFID tags



(a) N = 1000, with laser range finder (b) N = 1000, with particle filter only
Fig.5. Tracking error with / without laser-range-finder

VI. CONCLUSION

In this paper, we proposed RFID tags distribution strategy that is based on the geometrical segmentation with the Voronoi diagram. When the number of RFID tags is not sufficient to cover the whole map with patterns, the proposed method still aid the estimation of particle filter.

VII. ACKNOLEDGEMENT

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