Combination of RFID and Vision for Mobile Robot Localization

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Abstract

This paper illustrates an efficient method for global localization incorporating signal detection from artificial landmark consisted of RFID tags, and for fine localization incorporating feature descriptor derived from a view of scene. The system incorporates a RFID reader on a mobile robot checking the signal from RFID tags to localize the robot with respect to global position. After determining the global position of the robot, the feature matching can be used to checking the local position of it in a predetermined global position. And we propose a successive global-to-fine localization algorithm using RFID tags and feature matching respectively. The experimental results showed the proposed algorithm has improved the localization performance on indoor environments with a mobile robot.

1. INTRODUCTION

We describe a new localization method for an indoor mobile robot to move autonomously to the goal position. A key idea of our localization system is to fuse the Radio Frequency Identification (RFID) and the vision sensor. A mobile robot can recognize the region belonged to itself from the RFID system and get the information of the orientation and exact position of itself from the vision sensor.

The localization is very important issue for an indoor mobile robot. A mobile robot can't execute all operations related with the navigation without the localization information. As a mobile robot moves through its environments, its actual position and orientation always differs from the position and orientation that it is commanded to hold. Additionally, in the case of the kidnap, a mobile robot needs certainly the position and orientation. For the problem of determining location, many authors have studied a variety of approaches from the classical method like the map building using the mechanical sensor like the ultrasonic sensor to the newest method like the RFID. But, the map building method is very critical to the kidnap and has a disadvantage like the dead-recognizing.

In recent years, the RFID system has started to use the localization field of a mobile robot. G. Kantor and S. Singh used the RFID system for mapping. They rely on active beacons which provide distance information based on the time required to receive the response of a tag. And the positions of the tags have to be known more or less accurately [1], [2]. D. Hahnel, W. Burgard and D. Fox studied to improve the localization with a pair of RFID antennas. They presented a probabilistic measurement model for RFID readers that allow them to accurately localize RFID tags in the environment [3]. And T. Tsukiyama proposed a navigation system using RFID tags and a vision system with a single camera. The vision system provided feedback to make necessary corrections to the robot's movements and RFID tags used to be landmarks [4], [5].

In this paper, we classified into two topics about the RFID system and the vision sensor. The remainder of this paper is organized as follows. In section II, we will describe generally the RFID system and propose a new global localization algorithm using RFID tags. The vision sensor for the position and orientation of a mobile robot is described in the section III. The experimental environments and results will be presented in the section IV. We concluded with a few remarks about the advantage of the presented idea and we outline our future work in the section V.

II. RFID SYSTEMS FOR GLOBAL LOCALIZATION

A. Introduction of RFID

The RFID is a generic term for technologies that use radio waves to automatically identify people or objects with tags. An RFID system shown in Figure 1 included a mobile robot, is composed of a reader (or receiver), an antenna and a tag. RFID tags contain a few circuits that gain power from radio waves emitted by readers in their vicinity. So far, RFID application have been limited to the fields of recognizing people or objects with tags, mostly for deciding whether or not some objects in question are present in the vicinity of a reader.

RFID tags are classified by active one and passive one. Although they often considered together and are discussed interchangeably, active tag and passive tag are fundamentally different technologies. While both use radio frequency energy to communicate between a tag and a reader, the method of power the tags is different. Active tag uses an internal power source (battery) within the tag to continuously power the tag and its RF communication circuitry, whereas passive tag relies on RF energy transferred from the reader to the tag to power the tag. In this paper, we applied our idea using the active tag.

B. Properties of Active RFID

Active RFID has both advantages and disadvantages. Active RFID has the ability to detect objects at a long distance because it has an internal power sources. One more advantage of an active RFID is available that can dynamically store much more data than a passive RFID within the tag. Because of power limitations, passive RFID only provides a small amount of read/write data storage, on the order of 128 bytes or less. On the other hand, active RFID has the flexibility to remain powered for access and search of larger data spaces, as well as the ability to transmit longer data packets for simplified data retrieval. Active RFID tags are in common use with 128K bytes of dynamically searched read/write data storage. The mobile robot with the RFID system has the ability to detect the tag in the long distance and to provide enough memory to write much information in the tag.

While, the disadvantage is that the signal of active RFID is limited in the propagation ability. Active RFID uses high frequency between 100MHz and 2.4GHz to improve the detecting range of the tag. Therefore, active RFID to operate in and around obstacles is very critical. The ability for signals to propagate within crowded environments is also dependent on the wavelength or frequency. Active RFID signals propagate "around" rather than "through" the obstructions by means of diffraction, and the level of diffraction is dependent on the size of the object versus the signal wavelength. Diffraction occurs when the wavelength is approaches the size of the object. Additionally, because of the capacity of active tags, the robot can detect wrong tags which represent the other region or objects [13].

For that reason, in the normal indoor environment, Active RFID is not recommended for the most applications. But, resolving these problems, in the following section, we introduce a new global localization algorithm using the weighted RFID tag.

Figure 1 shows a prototype of the mobile robot with RFID reader and tags.

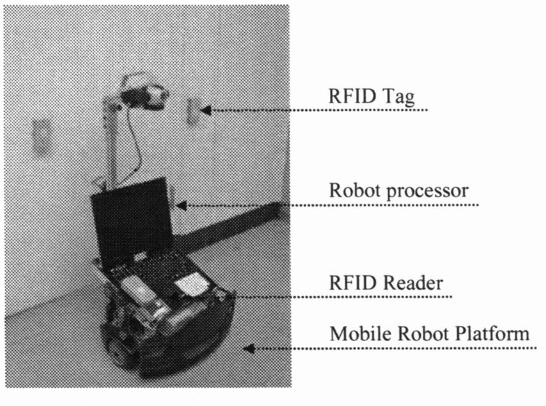


Fig. 1 Prototype of Mobile robot with RFID reader and tags

We have used ER-Scorpion as a mobile robot with a single web camera, and IDTec's 915MHz RFID tags as artificial landmark. Figure 2 illustrates the sensitivity map of the RFID system. Since the RFID tags can be detected 6m from the robot.

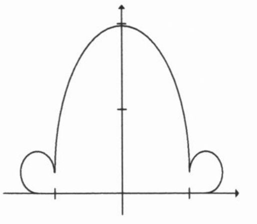


Fig. 2 Illustration of estimating distance from two successive images

C. Global Localization Algorithm using Active RFID

This section describes the global localization algorithm that runs to get more stably the region where the mobile robot lies. The existing method for the global localization using RFID is the voting skim that is to count the RFID tag detected in the region. Although the voting skim is very simple method, the performance is very wrong, particularly where it is applied in the boundary of the regions. Therefore, we propose the new global localization algorithm.

The key idea of proposed algorithm is to assign the different weight to the tags which are detected by the mobile robot reader. All tags have the different weight that was fixed with the tag position in the region. For this algorithm, the environment that a mobile robot navigates will be divided into several regions by user. And, on the divided region, the tags are attached on the wall or objects and assigned the weight. The weight value is fixed on the basis of the distance from the boundary of the region to the tags.

The summation of weighted tag P means the candidate of a region. The candidate P_k can be written as,

$$\begin{aligned} & P_k = w_1 \sum_{i=1} t_i + \ldots.. + w_n \sum_{i=1} t_n \\ & k,\ i = 1\ldots..n \qquad (1) \\ & R = \max(P_k) \end{aligned}$$

The variable k means the number of the region. The region R belonged to the robot can be calculated using the condition $\max(P_k)$ from the equation (1).

To show the feasibility of our idea, we established the tags in the laboratory shown in Figure 3. For the global localization, we split the whole experimental environment into three regions which have about 20 cells and each region has about 10 tags that are attached on the wall. The weight value is fixed on the basis of the distance from the boundary of the region to the tags. The range of the weight value is from 1 to 3 in the experiment.

The experimental results of the global localization algorithm will be described in the section IV.

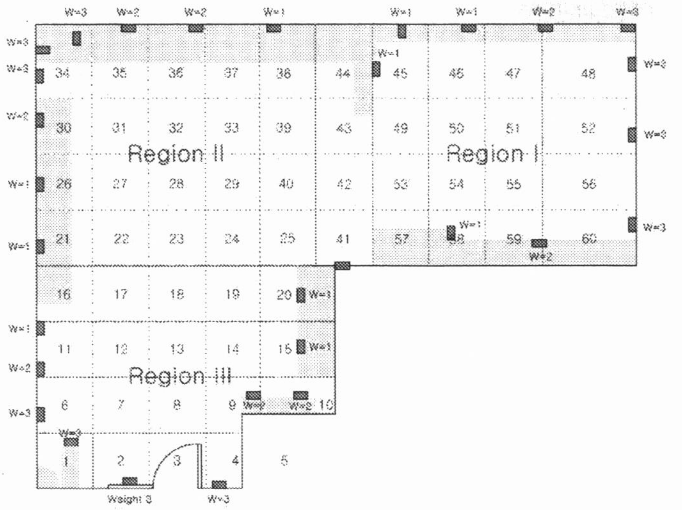


Fig. 3 Indoor environment attached to RFID tags

III. Vision Sensor for Fine Localization

A. Feature Descriptor

In this paper, the Scale-Invariant Feature Transform (SIFT), developed by Low [6] is employed. SIFT feature provide enhanced stability against variation due to pose and illumination, as well as viewpoint-invariant descriptors for matching in the presence of changes in scale and rotation in the image.

The feature descriptor is used to localize the mobile robot in a specific region which is determined by checking artificial landmark as global localization process. In this paper, SIFT is computed for 8 orientation planes and each gradient image is sampled over a 4x4 grid of locations, as a result feature descriptor is of dimension 128.

B. Distance estimation

The comparison of feature descriptor makes it possible finding the best image in the visual map. However, the result image simply indicated the current view angle of robot. The more accurate estimating position is needed to increase the localization performance. It obtained from estimating distance from current view image by two neighborhood images. Given two neighborhood images with its own relative angle to reference orientation and distance of two images in space, the distance from current position to the best finding image is calculated by equation (2).

$$r_1 = \frac{d}{k\cos\theta_2 + \cos(\pi - \theta_1)} \tag{2}$$

,where r_1 is distance between the current position of robot and the center of matched image, d is distance from two neighborhood images in space, k is $\sin(\pi-\theta_1)/\sin(\theta_2)$, θ_1 is a relative angle of first image, and θ_2 is that of second image. Figure 4 illustrates their relations.

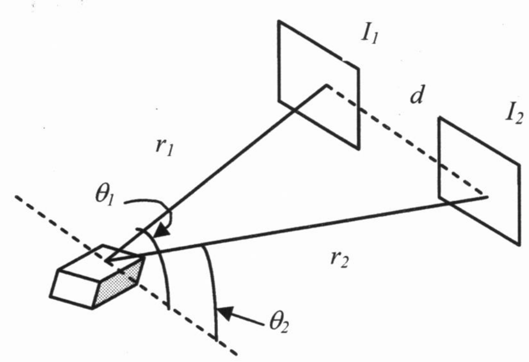


Fig. 4 Illustration of estimating distance from two successive images

IV. Experiments

The experiment is consisted of two stages; one is building a visual map with known position of each RFID tags and the other is testing localization. In the first stage, before collecting images for building visual map, the experiment environment is divided into several regions for testing global localization. The each region has representative RFID tags indicating the region where the mobile robot is in during navigating the environment. The number of representative tags are determined by how to discrete the region without interference of frequency.

The environment is divided into 3 regions considering its structure as depicted Figure 3.

A. Building Visual Map

After dividing environment into several regions, we have captured images in each region from a single camera. In capture process, the robot is located at center position in each region and rotates 360 degrees with 18 steps. After the feature descriptor is computed at each image, the visual map is build, which has 5 components in each DB element: element ID, region ID, angle, image, and feature descriptor. The angle is provided the position of image in a certain region representing the orientation with respect to angle of reference image of the region. Additionally, the reference map is built for aligning the orientation of the robot at entering each region. In experiment, 19 images are consisted of visual map in each region, as well as building reference map containing 3 images from collected images.

The numbers of RFID tags are totally 30, which 11 tags are in region I, 9 tags in region II, and the rest of tags in region III, respectively. The determination of number of tags in each region is based on decreasing interference of each other due to its high frequency emitting, as well as minimizing the number of detected tags which are not in current region. The topological structure of environment plays a key role on deciding how many tags are needed for it.

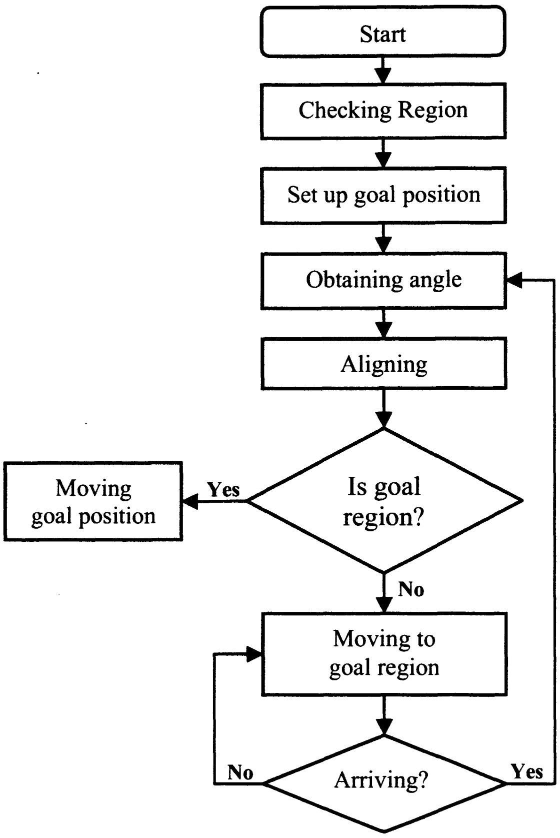


Fig. 5 Robot navigation flow of both localizations

B. Localization

The goal of using RFID tags is to achieve accurate global localization performance with a mobile robot, at the same time, that of feature descriptor is to increase fine localization performance with it. Given a set of RFID tags and feature descriptors, the task of robot localization can be performed by applying region decision-maker and descript match described aforementioned sections.

When the robot is located at a certain position in environment for staring to navigate from it to a specific position selected by user, the robot is checking the present region obtained by reading RFID tags. The goal position is determined by selecting the image with description which explains the objects in it, and the global position is obtained by selected image. The navigation path has to be calculated by start and goal position as simple as in order to avoid the complexity of calculating optimal path for fast moving. It means that any related algorithm for extracting optimal path does not imply on obtaining better localization performance, however, the experiment is mainly focus on localization itself. After acknowledging the current position, it is needed to align the robot to the reference orientation because of designing its moving scenario with respect to start and goal region. To align the robot to the reference orientation in present region, we have used the feature descriptor for matching the current viewing scene and a set of image of present region in visual map. The closet matched image is assumed to current viewing image and the angle is obtained from it for determining the degree of turning in order to change the current view is as much as same to the reference orientation image. When finding the reference image, the current orientation of the robot is assumed to the same of reference orientation in present region, and then starts to move to goal position. During the movement, the robot has performed to checking the region through reading RFID tags until entering the goal region in relation with goal position. The entering the goal region indicated the robot is located in near goal position, however, it does not know the current orientation because of occurring to avoid the obstacles during movement. The aligning orientation process performed again as similar as done in start stage as mentioned before followed to find the orientation of goal position and moved to it. Figure 5 illustrated the flow chart of navigation process.

When matching between the current view and images in visual map, in spite of matching descriptors would reduce the complexity and time consuming, there are some redundancies in matching whole images in visual map to select having maximum match count in the previous work.[][][]. As we suggested in this paper, acknowledging current region by indicating RFID tags has an important role to reduce the search range in finding the maximum correspondent image, as a result, it would be possible to find more accurate images to give a key for recognizing the current position of the robot.

C. Experimental Results

As describing in the section II, we propose the global localization algorithm. Figure 6 shows the experimental results of the new algorithm and the voting skim method. The x-axis means a region divided into a cell and y-axis is the success rate which is an accurate matching ratio between the measured region through reading RFID tags and ground-truth data in each cells. The dotted line means the results of the voting skim methods and its success rate is 79.4% on the average. On the other hand, the solid line is our global localization algorithm whose success rate reaches 91.5%. Consequently, the performance is improved about 12%.

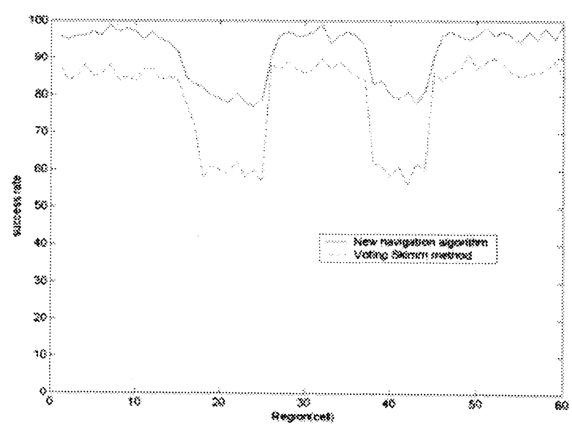
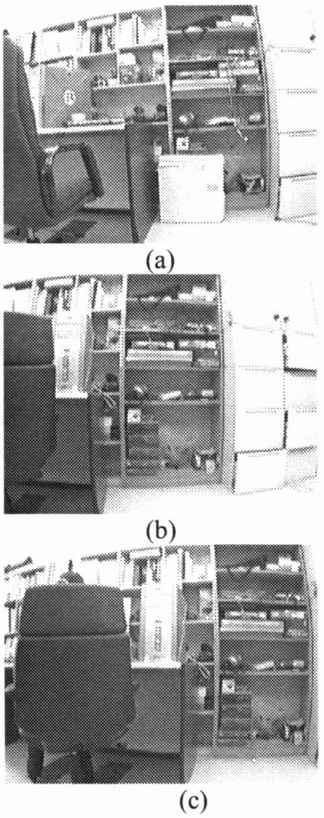


Fig.6 Success rate of the new algorithm and the voting skim method to detect the region from RFID tags



(a)

(b)

(c)

Fig. 8 The example result of feature matching including distance estimation: (a) current viewing scene with estimated distance is 2.56, (b) the best matched image from map with distance 2.4, (c) the neighborhood image of (b) with distance 2.7

In the boundary of the region, both success rates are relatively low because of the interference of the unwilling tags. But, the new algorithm performance is higher about 20% than the voting skim in the boundary.

The fine localization performance is measured by relative distance and angle between the estimated position of robot and that of the best matched image. The current distance of robot from the best matched image is calculated by (2) and the current viewing angle is obtained by angle of it. To validate localization performance using feature descriptors, an additional set of images were collected from random position, constrained to lie anywhere within the space from which images in visual map were collected before. The validation images were used to compute the distance from matched image in visual map using (2), estimates of the robot's position, and these estimates are compared against the ground-truth position. Figure 7 plots for location of estimated position for the validation image against the ground-truth position by joining the two points with a line. The length of line corresponds to the magnitude of error. Table I shows the mean error of distance and other statistical information as testing in region 1 of our environment. The larger error in distance is mainly due to incorrect angle from false feature matching when estimating distance. Otherwise, there is no error in terms of angle as illustrated in Figure. 7 because the estimated angle came from that of best matched image assuming the current view was the same as it. Reducing the error in distance could be performed building the visual map with more images in order to increase more overlaps between them as covering the environment as whole. The one test image and two neighborhood images from visual map depicted Figure 8. As mentioned before, the estimated angle coming from the best matched image is slightly different from current angle. However, the location of robot is nearly around the angle for assuming viewing current scene as same as the best matched scene. In this case, the estimated distance is 2.56 and ground-truth distance is 2.4.

TABLE I.
SUMMARY OF LOCALIZATION RESULTS

	Region 1
Images in Map	19
Space(m)	6.2x7.8
Validation image	19
Mean error(m)	0.23
Minimum error(m)	0.53
Maximum error(m)	0.01
Median error(m)	0.17

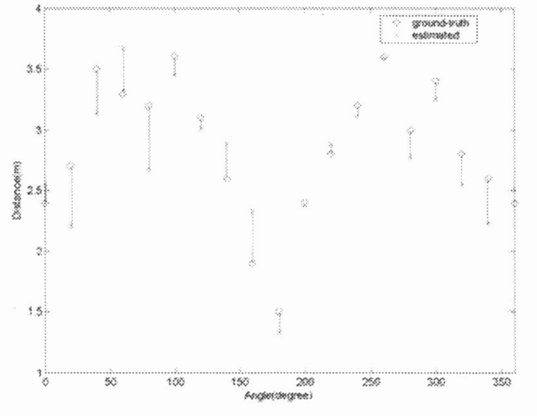


Fig. 7 Localization performance between estimated position (x) and ground-truth position (o)

V. CONCLUSIONS

Localization is a very important issue for indoor mobile robots. As a mobile robot moves through its environments, it should always be able to recognize its actual position and orientation. We thus proposed a new localization method using RFID tags and a vision system. RFID tags are used for detecting the region and the vision system provides the fine position and orientation of the mobile robot.

Our future work will focus on three areas: (i) reducing the number of RFID tags to install in an indoor environment, (ii) reducing the size of indoor regions detectable by RFID tags, and (iii) improving the correctness of the RFID-based region detection algorithm.

In order to achieve these goals, we will use a pattern recognition approach to the region detection problem. That means we treat the set of RFID tags as a feature vector, where 1 indicates that the tag is detected and 0 indicates that the tag is not detected, and also regard the regions as classes. Then we can apply a standard pattern classification algorithm to decide which region a RFID tag detection pattern belongs to. This approach will obviously increase the performance of the RFID-based region detection method, in terms of both the correctness of region decision and the size of regions.

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