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An Indoor Location Tracking using Wireless Sensor Networks Cooperated with Relative Distance Fingerprinting

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Abstract

We present a method of moving path control of an automatic guided vehicle (AGV) in an indoor environment through recognition of markers. A linear relationship between the relative distance to a marker from the current location of an AGV and the size of the recognized marker image can be built. Thus using the length of the recognized marker image as a fingerprint instead of the received signal strength (RSS) may result in a more reliable estimation of the location. Our simulation results show that the maximum localization error is less than 2cm and thus the range of the estimation error is ±0.025%. The main advantage of the proposed system is that they are highly flexible for on-demand delivery to any location.

Keywords: Automatic Guided Vehicle, Finger Printing Algorithm, Location Tracking, Marker Recognition

1. Introduction

In a modern crematorium, an AGV can transport a dead body safely from the loading place to its rightful destination, i.e., a designated furnace, or vice versa. The entire moving path is divided into two distinct sub-paths: *straight-line sub-path* and *rotating sub-path*. In the straight line sub-path, it can move forward until it arrives at the start location of the rotating sub-path. On arriving at that location, it changes its direction towards the designated furnace.

The existing AGV moving control system using infrared-ray sensors and landmarks have faced at critical problem. Notice that a crematorium has a narrow indoor environment compared to typical industrial fields. Particularly when an AGV changes its direction to enter the designated furnace the information provided by guided sensors cannot be utilized to estimate its location because the rotating space is too narrow to get them. One possible soultion is that a set of two reference points, a start location and an end location, ought to be found first by recognizing their correspoinding landmarks and then its wheel moving trajectories during rotation are computed next. After that it should be controlled precisely to move along the pre-computed trajectories. Since there are several landmarks to be recognized at the same time, it is necessary for each candidate to perform complex comparison operations to find which one is the best. However, because the time to be elapsed to complete rotation is very shorter than we expected, it is not possbile to select one by doing such complex operations in time.

In this paper, a marker-based relative distance fingerprinting algorithm is presented to resolve the above problem. We will briefly explain our proposed approach by considering a simple example. Let us assume that an AGV at the time *t1* is located at the distance *d1* from a marker as shown in Figure 1. At that time, the length of one side of the marker image recognized by its embedded vision sensor is l_{t1}. At *t2* (>*t1*), the AGV approaches that marker more closely (*d2*<*d1*), and the length l_{t2} of the recognized marker image is longer than l_{t1}. In other words, as the relative distance from its current location to the corresponding marker is shorter, the length of the recognized marker image becomes longer. In a simple point of view,

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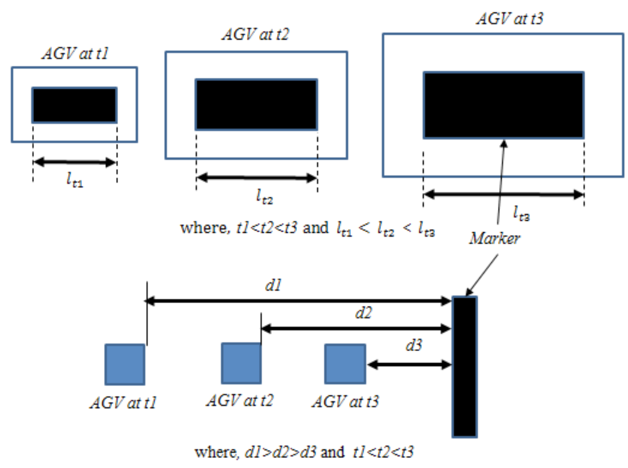

Figure 1. A recognized image size variation of a marker with respect to each AGV move.

a linear relationship between the distance and the size of the recognized marker image can be built. Thus using the length of the recognized marker image as a fingerprint instead of the received signal strength (RSS) may result in a more reliable estimation of the location. We call this approach a relative distance fingerprinting.

Before an AGV reaches a start location of a rotating sub-path, it tries to reduce its speed and then prepares to change its direction through the marker recognition. By doing so, the possibility of over-running the target location will be considerably reduced. Notice that recognizing a marker provides an AGV two pieces of useful information: one is the distance to the marker and the other is a direction of rotation. For example, the character 'R' written in a marker indicates a rotation to the right. Therefore, we present a relative distance fingerprinting algorithm to more precisely control of an AGV. Notice that because the maximum distance for recognizing a marker correctly is limited to a specific range, marker recognition is not always possible in the entire workspace. In most cases, the AGV moves along the designated path by recognizing landmarks. Upon entering a rotating sub-path, both the identification of a marker and fingerprinting are used to precisely control the AGV. These two different types of sensors cooperate to precisely control the moves of the AGV.

The rest of this paper is organized as follows: Section 2 summaries related works. We describe a marker detection algorithm using object contour extraction in Section 3. Section 4 presents the simulation results used to validate the proposed method. Finally, Section 5 concludes our work.

2. Related Works

2.1 Infrared sensors based Indoor Location Tracking System

Matthai et al.[1] proposed an approach to generate maps of RFID tags using mobile robots. They presented a sensor model that enabled the computation of the likelihood of the tag directions given the relative position of the tag with respect to the robot. However, their position error was too high, even though the average speed of 0.225m/s of the test robot are higher than that of our AGV. The method[9] of recognizing the locations of a mobile robot by using barcodes as landmarks was proposed. However, this method has the weakness that the location estimation error may vary from centimeters to meters due to the limitation of the performance of the recognizing instrument.

2.2 Artificial Landmarks

For successful navigation, an AGV must estimate its current location with respect to its immediate surroundings. An artificial landmark is a very simple and powerful tool for self-localization in indoor environments[3,4]. The landmark used here is composed of a 4 × 4 array of rectangles.

2.3 Fingerprinting Algorithm

The radio-frequency fingerprinting process requires multiple radio transmitters and receivers to be deployed to provide overlapping coverage of an area. The sensor located at fixed infrastructure points nodes to model a physical space in terms of the radio signal strength values by periodically broadcasting radio packets periodically to the air. The fixed base station sensor nodes are known as 'fixed node' in this paper.

RSSI may be considered as the simplest and cheapest method amongst the wireless distance estimation techniques, because it does not require additional, costly hardware for distance measurements. A known theoretical or empirical radio propagation model is used to convert the radio signal strength into the distance between a radio transmitter and a receiver. Assuming that the fixed position of the transmitter is known, the position of a mobile wireless receiver node can then be estimated by using a least squares algorithm. However, in practice, the radio signals are highly variable and unstable under the influence of environmental noises, obstacles, interference and the types of antenna. The signal strength is too sensitive to the harsh and dynamic indoor environments due to multipath fading and interference, which causes uncertainties in the radio communications amongst the wireless nodes. This condition makes it difficult to model the path loss, and thus the RSSI mathematically, which influences the positioning accuracy.

3. A System Cooperated with Relative Distance Fingerprinting

3.1 Overview

When the AGV reaches the rotate sub-path, it can be self-localized by using the landmarks. There are two possibilities of disposing the landmarks in the space. First, as shown in Figure 2(a), we can arrange the landmarks such that there is no landmark on the rotating sub-path. Notice that the circle centered on the landmark represents the possible detection range of the infrared sensor. This placementof the landmarks can cause a dead zone in which the landmarks are not detected by the sensor. Therefore, with this placement, the AGV should obtain the two reference points, a start location and an end location, before a rotation, and then should be controlled precisely to move along the resulting trajectories computed by using them. However, this placement cannot avoid either over-running or under-running of the AGV. Second way is to deploy the landmarks more closely in the space as shown in Figure 2(b), mainly at important places such as corners and entrance of the straight line sub-path. This placement results in duplicate recognition of the landmarks with the opposite direction. Typically, in the case of these placements, the AGV moves at a constant velocity v_c.

We need another solution to locate the AGV in the dead zone. In our system, we adopts marker identification to solve this problem, which is a relative localization method based on the relative distance to a marker. Let us assume that a maker is placed on the proper position as shown in Figure 3, and the AGV can recognize the marker. On identifying the marker, it is possible to estimate the current location of the AGV through the relative distance fingerprinting to be described later. The relative distance fingerprinting has the problem of the limitation on the possible range of marker recognition but it gives a fairly accurate information for the remaining distance. Notice that the AGV can adjust its velocity to prepare a rotation as soon as it recognizes the marker. Therefore, it can avoid either over-running or under-running of the AGV.

3.2 Marker Identification

Note that because the marker is a planar object, we set the *z* coordinate to 0 (the marker is placed on the *XY* plane, centered at the origin). There are different methods to

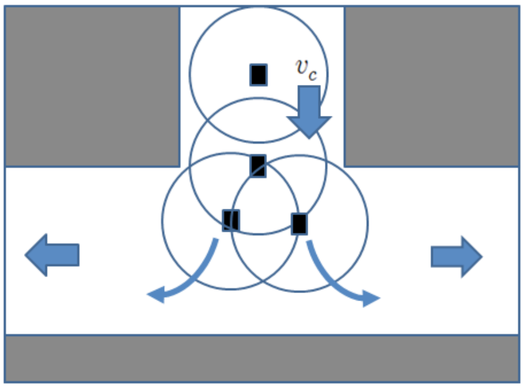

Figure 2(b). The placement of the landmarks with overlapped zone.

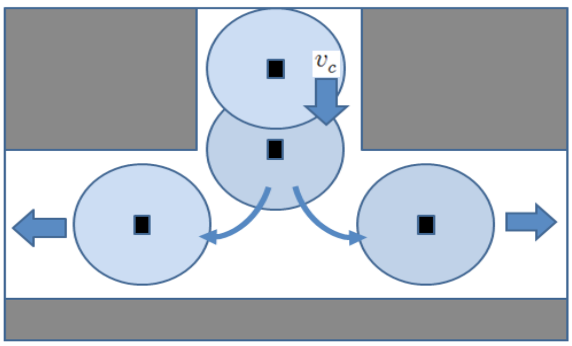

Figure 2(a). The placement of the landmarks with dead zone.

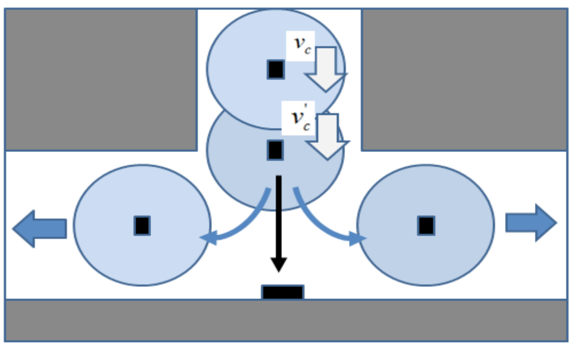

Figure 3. The placement of landmarks with dead zone and a marker.

detect a marker in an image. The most simple and fast method is to perform the following steps:

3.2.1 Image Binarization

The first step is to convert a colored image into a binary image. The simplest way to binarize an image is to convert it to a gray scale image I_g, in which every pixel can take only 256 possible values. The algorithm process I_g to produce a new image I_b, in which every pixel has only a value of 0 or 1.

3.2.2 Component Labeling

We use a local thresholding algorithm. This algorithm allows the user to use the marker under very different conditions. The local thresholding algorithm uses a N × N window centered at each pixel of I_g to compute the threshold for that pixel. One of the advantages of constant thresholding is that it produces images with more uniform regions of black or white pixels, thereby lowering the number of connected components. This lower number of components accelerates the performance of the component labeling algorithm.

3.2.3 Marker Verification

After extraction of the contours, the image was segmented with respect to the rectangles extracted. Using a contour tree, the inclusion relationship is checked to verify the correctness of the markers.

3.3 Location Estimation using Relative Distance Fingerprinting

The proposed fingerprinting approach consists of a data collection process in which, the size of a marker image recognized at each fixed reference point is measured and stored. The maximum distance between a marker and the current location of an AGV that allows a successful detection strongly depends on the size of a marker. Notice that when the AGV enters the area in which it is not possible to detect a marker image, it can move along the designated path by obtaining the information provided by wireless sensor nodes.

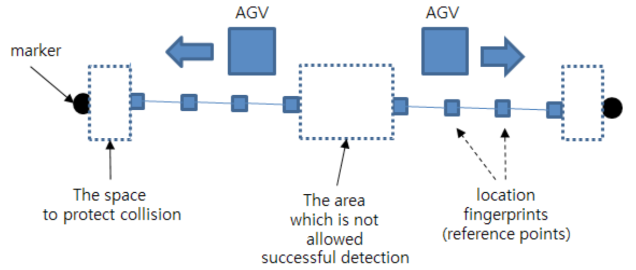

Figure 4. An example of the reference points used to determine their fingerprinting information during the data collection process.

Following the setup process, an AGV may be localized using the image size measured at each reference point. The location estimation using relative distance fingerprinting can be performed on a line-segment basis. As shown in Figure 5, given the set of n reference points, the entire line along the x-axis is divided into $n - 1$ line segments. For each line segment the slope Δ can be obtained using two reference points and the fingerprinting already measured. Notice that the slope of each line segment can be saved in the database together with the fingerprinting information.

The slope Δat the i-th segment can be calculated using the following equations:

$$\Delta_{y_{i+1}=y_i} = \frac{fp_{i+1} - fp_i}{x_{i+1} - x_i}, \quad \Delta_{x_{i+1}=x_i} = \frac{fp_{i+1} - fp_i}{y_{i+1} - y_i}$$

Given the image size measured $fp_{measured}$, the x-coordinate $x^{expected}$ and the y-coordinate $y^{expected}$ of the estimated location for an AGV is obtained by the following equation:

$$x^{expected} = x_{\min} - \frac{fp_{\min} - fp_{measured}}{\Delta_{y_{i+1}=y_i}}$$

$$y^{expected} = y_{\min} - \frac{fp_{\min} - fp_{measured}}{\Delta_{x_{i+1}=x_i}}$$

$$fp_{\min} = \min[fp_i, fp_{i+1}], \ x_{\min} = \min[x_i, x_{i+1}],$$

$$y_{\min} = \min[y_i, y_{i+1}]$$

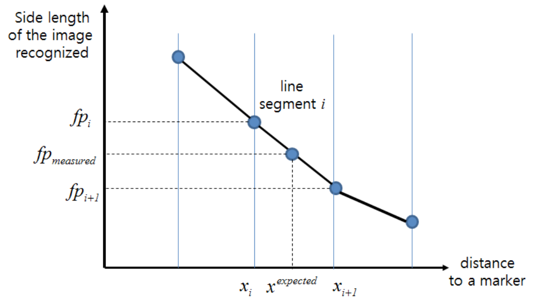

Figure 5. A piecewise linear location estimation of an AGV using relative distance fingerprinting.

3.4 The Overall Localization Process

Basically, most of the motion control of the AGV will be performed through landmark tracking based on double landmark recognition. When the AGV identifies one the markers, the AGV can be controlled through relative distance fingerprinting. In the case of operation with relative distance fingerprinting, the velocity of the AGV can be determined depending on the remaining distance to a marker.

4. Experimental Results

4.1 Experimental Set-Up

For the laboratory tests, a mock-up of an AGV is used. The AGV contains an ATMega 128L microcontroller and DC motors. In addition, both infrared sensors and a CMOS image sensor are installed. Notice that an image to be captured will be saved as a motion JPEG file whose resolution is 160 by 120. We implemented a prototype system using Visual C++ language and Open CV libraries. In these experiments, three different sizes of markers are used: 10 cm × 10cm, 15cm × 15cm, and 20cm × 20cm. The number of reference points was determined on both the AGV speed and the marker size.

4.2 The relationship between the marker size and the distance to the marker

A set of experiments to analyze the relationship between the marker size and the maximum allowable distance from the marker to recognize it successfully are performed. Table 1 shows the maximum distance with respect to the corresponding marker size. With 5cm increases of both sides of a marker, the maximum distance gets longer by approximately 1 m. With these values the AGV can recognize a marker over a reasonable detection time (typically less than 2 seconds). As indicated above, the marker detection range is restricted to a certain distance.

Table 1. The Relation of the marker size and the maximum distance

The Size of a Marker	Maximum Distance
10 Cm x 10 Cm	1.25 m
15 Cm x 15 Cm	1.75 m
20 Cm x 20 Cm	2.75 m

As shown in Figure 6, as the marker size gets larger, the elapsed time to recognize it becomes shorter as we expected.

Table 2 summarizes the relationship of the length of one-side of the recognized marker image and the distance to the marker. Notice that the marker size of 15cm × 15cm is used. As the mock-up AGV approaches a marker, the length of one-side of the recognized marker image gets longer. Thus, it can be possible to use the length of the recognized marker image as a fingerprint to estimate the relative distance to a marker. This relationship is to be built for all of the marker sizes as shown in Figure 7. Notice that

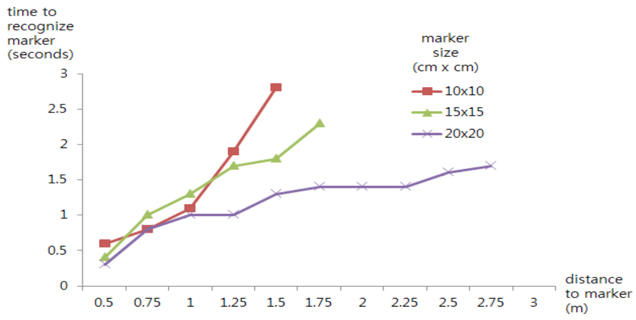

Figure 6. The time to recognize a marker with respect to the distance to the marker.

Table 2. The Relationship of the relative distance and its recognized image size

Relative Distance (m)	Side-Length of the Image (cm)	Variation (cm)	Percentage of the Marker to the Whole Image
2.0	0.5	–	0.43
1.5	0.9	+0.4	1.39
1.0	1.5	+0.6	3.87
0.5	2.4	+0.9	9.91

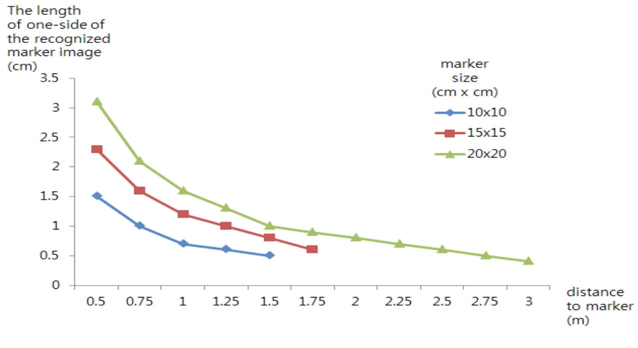

Figure 7. The length of one-side of the recognized marker image with respect to the distance to the marker.

the slopes of all of the curves are similar. Specifically the recognized image size rapidly increases as the distance to a marker gets shorter.

4.3 Location Estimation Using Relative Distance Fingerprinting

The experimental results on the location estimation errors that occur using relative distance fingerprinting are given as shown in Figure 8. Notice that two reference points, 0.5 m and 2 m, are excluded in this experiment, because the point at 2m is the start location of the mock-up AGV and the one at 0.5 m is the stop location for avoiding a collision. The general marker whose size is 15cm × 15cm is used and its current location can be measured in the unit of centimeters. At every 25cm, the AGV stores the recognized marker image for comparison. The maximum estimation error was 2cm and the error range is +0.025%. Specifically, the estimated location of the mock-up AGV is 1~2 cm ahead of the real location.

4.4 Measurement of the AGV's velocity using relative distance fingerprinting

We have tested the accuracy of the AGV's velocity estimation using relative distance fingerprinting. At the time of 6.7 and 14.6 seconds, the relative distance between the mock-up AGV and a marker was measured at 2.25m and 1.35m, respectively. Thus, the AGV's velocity is calculated to be 0.113m/second = 6.78m/minute. The real velocity is 6.75–6.80 m/minute. Therefore our estimation has a high accuracy of speed estimation.

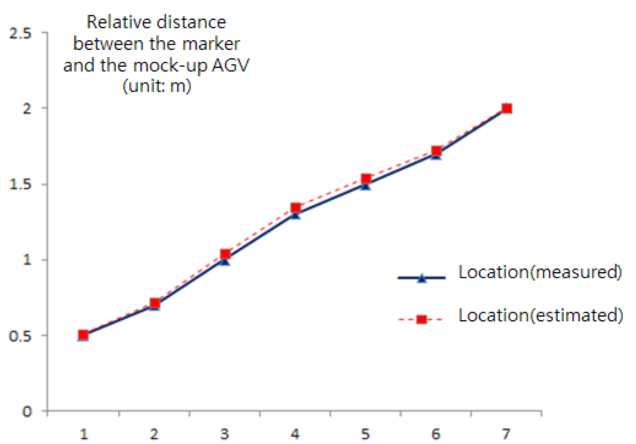

Figure 8. A comparison of the estimated location using fingerprinting with its real location.

5. Conclusion

For more precise control of an AGV in a crematorium, we proposed a method of relative distance fingerprinting which uses the length of the recognized image size for estimating the location. The estimation can be performed on a segment basis. This method will be used to assist the primary navigation method based on double landmark recognition. These two distinct navigation methods are combined and integrated into the application systems which manage both the motion control and the location monitoring of the AGV.

The proposed localization system provides the AGV with accurate and stable location information. The system can update location in real-time while the AGV is moving. The main advantage of the proposed system is that they are highly flexible for on-demand delivery to any location. They are also quick to install, with less down-time for the crematorium. The space covered by the system can be easily expandable, because localization sensor in the system communicates with sensors deployed on indoor environment.

6. Acknowledgement

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