Use of IRID (InfraRed IDentification) for Mobile Robot Localization

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***Abstract*—This paper presents mobile robot localization using IRID (InfraRed IDentification) as artificial landmarks. Different from RFID, IRID has highly deterministic characteristics. IRID is implemented with IR LEDs and photo transistors. By putting several IRID LEDs on the ceiling, the floor is divided into several sectors and each sector is set to have a unique identification. IRID tells which sector the robot is in, but the size of the uncertainty is still too large if the sector size is large, which usually occur. Dead-reckoning provides the estimated robot configuration but the error becomes accumulated as the robot travels. This paper presents an algorithm which combines both the encoder and the IRID information so that the size of the uncertainty becomes smaller. It also introduces a framework which can be used with other types of the artificial landmarks. The characteristics of the developed IRID and the proposed algorithm are verified from the experiments.**

I. Introduction

The number of potential applications for autonomous mobile robots in indoor/outdoor environments is increasing, ranging from maintenance and repair of mechanical machinery, to clean up operations for accidents involving hazardous chemicals and materials, to interchanging atomic fuel in nuclear power plants, to search and rescue operations in burning buildings or hostage situations.

Unlike manipulator robotics in many manufacturing applications, mobile robotics requires a global understanding of the environment and the ability to dynamically plan in it. There are some fundamental issues that must be addressed to achieve autonomous mobile robot navigation. First, a path planner is needed to select a route for the robot to follow. Second, since unavoidable odometer errors render it impossible for any mobile robot to precisely follow a planned trajectory, localization techniques are needed to precisely determine the robot's position and orientation.

Commonly, dead-reckoning (open-loop estimation) is used for intermediate estimation of position during path execution. Dead-reckoning is often used when wheel encoders are available for drive wheel position measurement. However, due to errors in kinematic model parameters, wheel slip, or an uneven surface, poor position estimates may occur. Lots of work have been done in mobile robot localization using range sensors, vision cameras, natural/artificial landmarks, indoor GPS, etc in order to reduce the errors from dead reckoning.

Recently, new types of sensors, networks and devices are getting popular in new domain called as Ubiquitous environment. RFID is one of those and is getting attention in material distribution, inventories, etc. Several research of mobile robot localization using RFID and wireless LAN have been done. Other types of artificial or natural landmarks have been widely used especially in vision society.

[1] provided methods of localization using multiple RF beacons that provide the ability to measure the range only. This method enabled an accurate estimation of robot location using Markovian probability grids and the known beacon locations. Similarly, [2] dealt with RF wireless network based system for locating and tracking users inside buildings. It uses multiple receiver locations' signal information to triangulate the user's coordinates by using both empirically determined and theoretically computed signal strength information. [3] developed inexpensive location support system which is indoor, mobile, location-dependent application by using RF signal and ultrasonic pulse from beacons spread throughout the building. They estimate distances to the different beacons using the difference in RF and ultrasonic signal propagation times, and therefore infer the space they are currently in. [4] proposed three dimensional position and orientation tracking system that combines infrared markers with a head-mounted stereo camera to detect the user's position, and an orientation sensor to measure the orientation of the user's head. They also used extended Kalman filter to reduce the error of multiple sensors. A localization method using ultrasonic and infrared signals at the same time is investigated by [5], and a method of personal positioning with self-contained sensors and a wearable camera is presented in [6]. [7] described a system that measures the orientation of user's viewpoint by an inertial sensor and the user's position using positioning infrastructures in environments and a pedometers. The system receives ID from RFID tags or IrDA markers to specify the user's position. In [8], to avoid problems like power supply or undesirable visual effect, a new localization method based on using an IR camera and invisible markers consisting of translucent retro-reflectors was introduced.

This paper introduces a new artificial landmark for localization. Instead of using radio frequency signal, infrared light is used in order to have the deterministic characteristics. In the following section, IRID is described and how to combine the IRID information with the dead-reckoning is explained in Section III with simulation results.

Experimental results are shown in Section IV followed by conclusion.

II. IRID (INFRARED IDENTIFICATION)

RFID has either 64bit or 96bit of information so that the number of possible identification is almost infinite. It is reported that RFID is being studied as artificial landmarks for mobile robot localization. However, due to the characteristics of the radio frequency signal, the signal strength and the distribution of the signal are highly stochastic (for example, positive/negative false readings) so that relying on the RFID reading only may even make the localization result even worse.

IRID is simply a set of an infrared LED and a photo transistor. The light is modulated at 38KHz, so that the photo transistor with a filter can get the light with less interference with fluorescent light and sunlight. Depending on the pulse train of the light, each LED can emit a unique ID. However, only one LED should be turned on at each time to avoid collision with lights from other LEDs. The following figure (Fig. 1) shows the concepts of the IRID. Three IR LEDs are installed on the ceiling and each delivers unique ID. The robot moves on the floor with a receiver.

The floor is divided into 6 different sectors as shown in Figure 2. A supervisory controller coordinates the firing of the emitters, so that there are two sectors (sectors 4 and 5 in Figure 2) where the robot receives two different identifications not at the same time, but sequentially, which are differentiated from the other three sectors (sectors 1,2 and 3 in Figure 2) where only one identification is received. The last sector (sector 6 in Figure 2) is where the robot receives no identification.

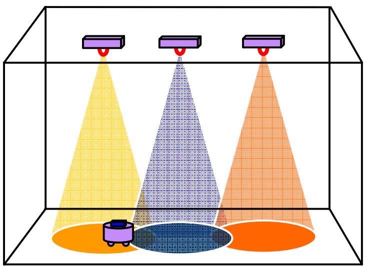

Fig. 1. Three IRIDs and a Mobile Robot

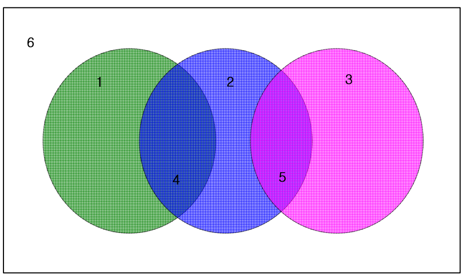

Fig. 2. Sectors based on Identification

III. DEAD RECKONING WITH IRID

It is well known that the size of the uncertainty in robot location grows larger as the robot travels [9,10]. The error should be reset before it becomes too large. For a differential drive mobile robot, the robot configuration can be estimated starting from a known configuration by integrating the movement.

The configuration vector, p is defined as

$$p = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \quad (1)$$

If right wheel and left wheel travels Δs_r and Δs_l respectively, then the new configuration is represented as

$$p' = \begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = f(x, y, \theta, \Delta s_r, \Delta s_l) = p + \begin{bmatrix} \Delta s \cos\left(\theta + \Delta\theta/2\right) \\ \Delta s \sin\left(\theta + \Delta\theta/2\right) \\ \Delta\theta \end{bmatrix} \quad (2)$$

where $\Delta s = \dfrac{\Delta s_r + \Delta s_l}{2}$ and $\Delta\theta = \dfrac{\Delta s_r - \Delta s_l}{b}$

Dead-reckoning results can give only a very rough estimate of the actual position. We assume that the errors of the individually driven wheels are independent and the variances of the errors of the left and right wheels are proportional to the absolute value of the traveled distances as the following equation,

$$\Sigma_{\Delta} = covar(\Delta s_r, \Delta s_l) = \begin{bmatrix} k_r|\Delta s_r| & 0 \\ 0 & k_l|\Delta s_l| \end{bmatrix} \quad (3)$$

then, the covariance matrix is represented as

$$\Sigma_{p'} = \nabla_p f \cdot \Sigma_p \nabla_p f^T + \nabla_{\Delta} f \cdot \Sigma_{\Delta} \nabla_{\Delta} f^T \quad (4)$$

where $\nabla_p f = \begin{bmatrix} 1 & 0 & \Delta s \sin\left(\theta + \Delta\theta/2\right) \\ 0 & 1 & -\Delta s \cos\left(\theta + \Delta\theta/2\right) \\ 0 & 0 & 1 \end{bmatrix}$

and $\nabla_{\Delta} f = \begin{bmatrix} f_1 & f_2 \\ f_3 & f_4 \\ f_5 & f_6 \end{bmatrix}$

$$f_1 = \frac{1}{2}\cos\left(\theta + \Delta\theta/2\right) - \frac{\Delta s}{2b}\sin\left(\theta + \Delta\theta/2\right)$$

$$f_2 = \frac{1}{2}\cos\left(\theta + \Delta\theta/2\right) + \frac{\Delta s}{2b}\sin\left(\theta + \Delta\theta/2\right)$$

$$f_3 = \frac{1}{2}\sin\left(\theta + \Delta\theta/2\right) + \frac{\Delta s}{2b}\cos\left(\theta + \Delta\theta/2\right)$$

$$f_4 = \frac{1}{2}\sin\left(\theta + \Delta\theta/2\right) - \frac{\Delta s}{2b}\cos\left(\theta + \Delta\theta/2\right)$$

$$f_5 = \frac{1}{b}$$

$$f_6 = -\frac{1}{b}$$

In this paper, the IRID information is being used to reduce the uncertainty size. Figure 3 shows a simple example. The size of the uncertainty becomes smaller if the IRID information tells the robot is inside the circle where the robot receives the infrared light (Figure 3). Even in case the robot does not move into the neighbor sector, but staying in a sector while getting the same IRID, the uncertainty size doesn't diverge because it is trimmed continuously.

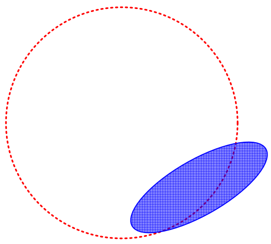

Fig. 3. Uncertainty of the Robot Location with Dead-Reckoning

Mathematically, this trimming is represented as the following equation. For simplicity, if we assume one-dimension, the configuration is estimated from,

$$\mu = \int_{-\infty}^{\infty} x f(x) dx \qquad (5)$$

In case the IRID tells the robot belongs to a region of $x_1 \le x \le x_2$, then, eq. (5) becomes

$$\mu^* = \int_{x_1}^{x_2} x f(x) dx \qquad (6)$$

Information is also available at the instant when the robot moves into another sector (crosses the border between two sectors). We can tell the robot is on an arc at the instant of the identification change. Therefore, the uncertainty size shrinks abruptly.

More important feature of using IRID is so called the back-propagation. In Fig. 4, the uncertainly grows from P1 to P2 as the robot moves (T12). Another movement (T23) makes the uncertainly grows from P2 to P3. Let's assume the robot gets ID#2 after completing T23 movement. The instantaneous transition from ID#1 to ID#2, which tells the robot crossed the red line, is not considered for explaining the back-propagation. Getting ID#2 means the robot is deterministically in Sector #2 and the uncertainly P3 shrinks to P3*. P3 does not represent the uncertainly any more but P3* does. Therefore, the previous step's uncertainty P2 is not correct. From the inverse transition I32, we can find P2*, a subset of P2 which would give P3* only.

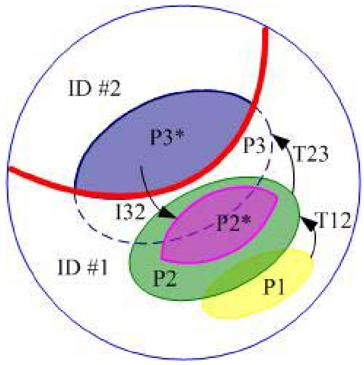

Fig. 4 Back-propagation

Be repeating this back-propagation whenever available, the uncertainly region becomes much smaller than simply being trimmed. Mathematically, back-propagation is getting the covariance matrix, $\sum_p$ from the following equation,

$$\sum_p = \left(\nabla_p f\right)^{-1} \left(\sum_{p'} - \nabla_\Delta f \bullet \sum_\Delta \bullet \nabla_\Delta f^T\right) \left(\nabla_p f^T\right)^{-1} \qquad (7)$$

All three ways of utilizing the IRID information (simple trimming, the instantaneous change of the ID and the back-propagation) are used in order to continuously make the uncertainty region smaller.

IV. Experiment

The most important feature of the IRID is its highly deterministic characteristics of receiving the identification (unique infrared light pulses) depending on where the receiver is located. A supervisory controller is used with several LEDs which controls the firing sequence for anti-collision and also for modulation of the light.

Four IR emitters are used with unique IDs so the workspace is divided into 14 sectors. The robot receives a unique ID of the sector in which it is currently located. Measurements of the IRID information is performed repeatedly and the following figure (Figure 5) shows the sector with its unique identification represented by color. The IR emitters are installed at 2m high from the floor. Each emitter covers a region with approximately 0.8m in radius. Even though the area is not perfectly circular, the location of the corresponding sector to each of the identification is deterministically known. Therefore, it is possible to decide the region in which the robot is represented in the global coordinates.

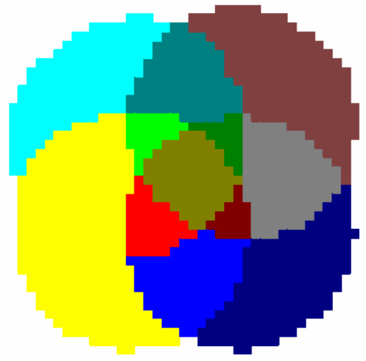

Fig. 5. Measured Sector with Four IRIDs

As shown in Fig. 6, a mobile robot with the receiver is used for experiments. The robot controller gets both the encoder and the IRID information while it is moving. The configuration of the robot is estimated on real time.

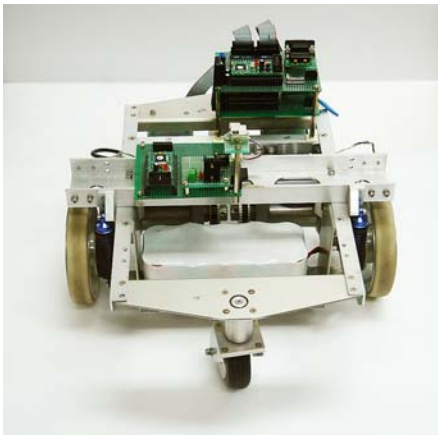

Fig. 6 Mobile Robot with IRID Receiver

Experimental results are shown in the following figures which clearly show the benefits of combining the identification information with dead-reckoning. Fig. 8 shows the nominal trajectory only from the encoder information (dead-reckoning). The values for the error constants are experimentally established by performing and analyzing representative movements of the robot as in [11]. The robot started on an arc where the robot began getting the IRID information (yellow). As the robot moves while getting the same IRID, the uncertainty grows but not as rapidly as the case without using the IRID information. Then, the robot gets different IRID (pink) so that the uncertainty resides in the neighbor sector. The next changes of the IRID are represented with red and blue. Therefore, the uncertainty becomes much smaller whenever it moves into another sector and the ultimate goal is to reset the error. As mentioned in Section III, even in case the robot keeps moving in a sector while getting only one IRID, the uncertainty doesn't diverge but gets even smaller because it is repeatedly trimmed. The red dot in the uncertainty represents the position of the robot estimated from dead-reckoning. The blue one is the centroid of the uncertainty region and this represents the estimated location of the robot based on the encoder and RFID information.

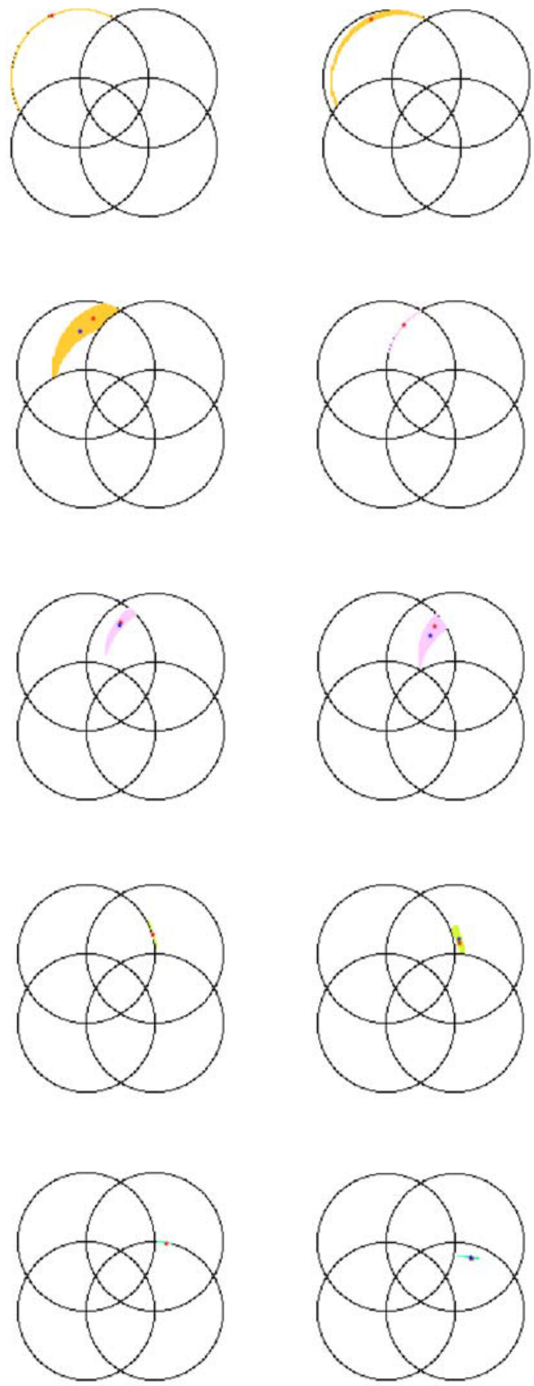

Fig. 7 Uncertainty of the Robot Configuration according to the Robot Movement and IRID Information.

Figure 8 shows the number of cells in uncertainty with respect to time. The number of cells is simply regarded as the size of the uncertainty. The robot passed three different sectors. At steps #19, #37, #45, the size abruptly becomes much smaller as the change of the ID is detected and the robot's possible location is on a part of an arc. We can see that the uncertainty doesn't grow continuously even while in a same sector. It is also clearly shown that the uncertainty is much smaller with back-propagation.

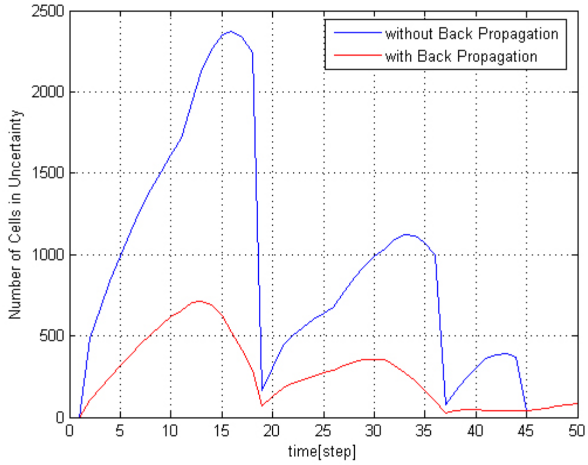

Fig. 8 Uncertainty Area Change

Fig. 9 shows the result of dead-reckoning (Encoder), estimated configurations combined with IRID (with and without back propagation) and the actual configuration. The proposed estimation may not provide continuous path especially when the robot crosses the border because it's the centroid of the uncertainty and the uncertainty becomes a part of an arc at that moment.

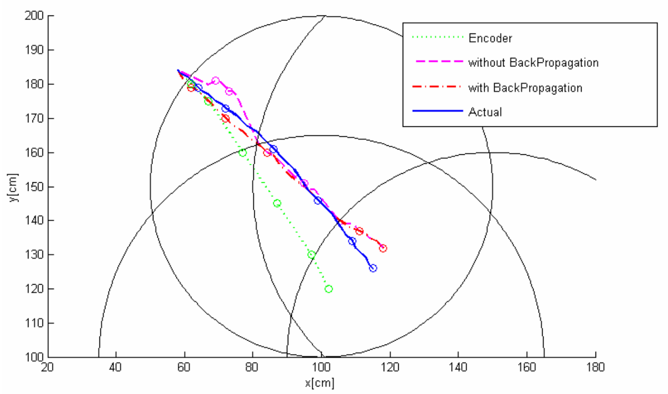

Fig. 9 Comparison of Robot Configuration

Figure 10 also shows the difference of results with and without using the IRID information after the robot passed several sectors.

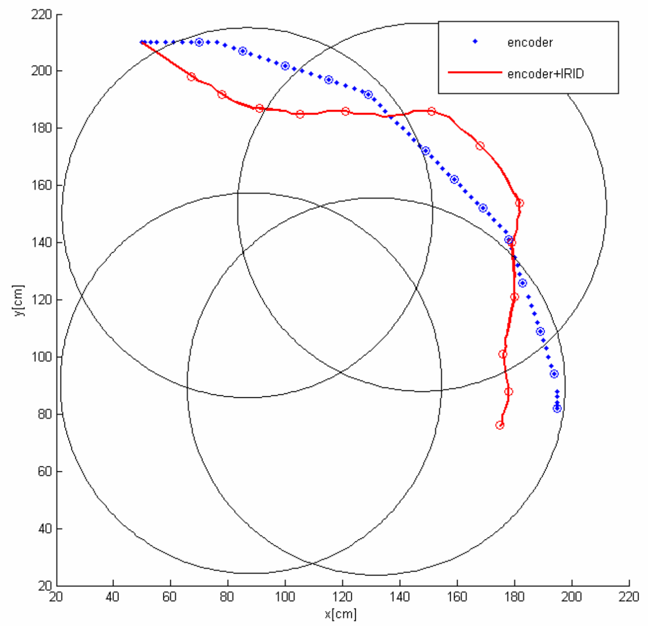

Fig. 10 Estimated Configurations

V. CONCLUSION

This paper introduces a localization scheme using IRID as artificial landmarks. IRID is built with the infrared emitters and photo transistors. It showed highly deterministic characteristics. Dead-reckoning result is combined with the IRID information in order to reduce the uncertainty of the robot configuration. Three different ways of utilizing the IRID information are introduced. Experimental results show the effectiveness of the proposed method.

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