Beacon Scheduling Algorithm for Localization of a Mobile Robot

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Abstract. This paper proposes the localization scheme using ultrasonic beacons in a multi-block workspace. Indoor localization schemes using ultrasonic sensors have been widely studied due to their cheap price and high accuracy. However, ultrasonic sensors are susceptible to environmental noises from their propagation characteristics. On account of their decay phenomena when they are transmitted over a long distance, ultrasonic sensors are not suitable for application in large indoor environments. To overcome these shortages of ultrasonic sensors while emphasizing their advantages, a multi-block approach has been proposed by dividing the indoor space into several blocks with multiple beacons in each block. This approach, however, is hard to divide into several blocks when beacons are not installed in a certain pattern, and in case of having newly installed beacons, all blocks placement is reconstructed. Therefore, this paper proposes a real time localization scheme to estimate the position of mobile robot without effecting beacons placement. Beacon scheduling algorithm has been developed to select the optimal beacons according to robot position and beacon arrangement for the mobile robot navigation. The performance of the proposed localization system is verified through simulations and real experiments.

Keywords: Mobile robot, Localization, Ultrasonic, Beacon, Beacon Scheduling.

1 Introduction

With the development of robot technology such as microprocessor, sensors and computer, the practical use of mobile robots is widely increased. Real examples are cleaning robots and tour guide robots in the indoor environments such as museum and exhibition hall. And at outdoor environments, patrol and exploration of the mobile robot to be used for various purposes have been developed. For service applications in various environments, position recognition, environments perception using sensors, obstacle avoidance and path planning for autonomous navigation is vitally necessary. Especially, the precise localization of the mobile robot is one of the most important issues in the robotics field.

Localization schemes of mobile robots are classified into two categories that is relative and absolute position estimation. Relative position estimation is dead

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reckoning method using odometry, gyro and accelerometer sensors [1], [2]. This method is easy and cheap to implement. However, with increasing driving distance, the accumulative error becomes larger, thus making precise localization difficult [3]. The absolute position estimation obtained using GPS, laser, infrared, vision, RFID, and ultrasonic sensors may resolve the problems of the relative position estimation [4-9]. However, it has problems due to the uncertainty of sensor information and the difficulty of installing the sensor.

This paper used ultrasonic sensors for indoor localization of mobile robot. The ultrasonic sensors have been widely used since they are cheap, easy to be controlled and have high accuracy. However, ultrasonic sensors are susceptible to environmental noises from their propagation characteristics. On account of their decay phenomena when they are transmitted over a long distance [10], ultrasonic sensors are not suitable for application in large indoor environments. To overcome these shortages of ultrasonic sensors while emphasizing their advantages, a new approach has been proposed by dividing the indoor space into several blocks with multiple beacons in each block [11]. As a representative scheme, the block ID recognition scheme has been developed by Ninety System to widen the operating area of the mobile robot [12]. However, in using this system, the user needs to specify all the coordinates of the active beacons and the block ID manually, which may lead to a high cost for the initial setting up of the working environment [18], [19]. Also, in case of unstructured placement of beacons or having newly installed beacons, dividing blocks to specify placement is difficulty and the placements of all blocks are reconstructed. The localization is not possible when the mobile robot moves out of the workspace, which is defined by the user a priori.

In this paper, a localization scheme in unstructured beacon placement has been proposed. The mobile robot is able to estimate own position using multi-block scheduling without effecting beacons placement. This paper is organized as follows. In section II, the indoor localization system, iGS, is introduced in detail, and a beacon scheduling algorithm in the multi-block environment is described in section III. In section IV, the effectiveness and usefulness of the multi-block scheduling algorithm has been verified by experiments. Finally, section V concludes this research work and mentions possible future related work.

2 Multi-block Localization Using iGS

2.1 Introduction to iGS(indoor GPS System)

The indoor localization system, developed by Ninety System and the Intelligent Robot Laboratory of PNU, has been utilized as a platform for mobile robot navigation. Its localization accuracy is ±5 cm and the localization period is 200 msec. The basic operating space is defined as 5 m (width) x 5 m (depth) x 2.5 m (height).

Figure 1 illustrates the navigational environment of the mobile robot in the iGS space. There are at least three active beacon sensors in the room and one localizer on the mobile robot. The localizer calls a specific beacon to send ultrasonic signals which are received by the localizer to measure the distance to the beacon. When such distance data from three known locations are available, the unknown location of the mobile robot can be estimated by the trilateration method [13], [14]. The localizer uses an RFID signal to select a specific beacon, which sends out ultrasonic signals to stably provide the distance data to the localizer. The distance from the localizer to the beacon can be easily obtained by the multiplication of the speed of the ultrasonic signal and the time of flight, even though the environment temperature changes the speed of the ultrasonic signal in a known pattern.

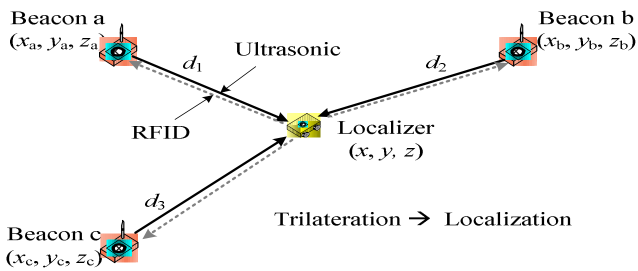

Fig. 1. Beacons in the iGS space

2.2 Distance Measurement and Calculation of the Absolute Location

The distance can be calculated by the multiplication of the speed of the ultrasonic signal and the measured TOF [15].

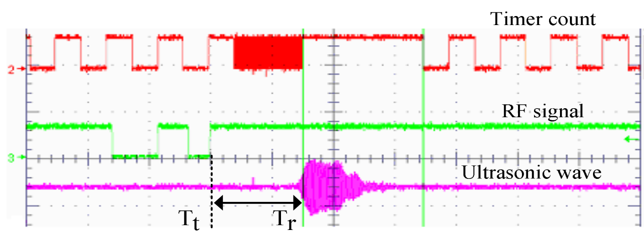

Fig. 2. TOF diagram

Figure 2 shows an illustration of the starting time for the counter, T_t, and the arrival time of the ultrasonic signal at the localizer, T_r, where the counter starts when the RF signal is transmitted and stops when the ultrasonic signal is detected by the localizer with a certain threshold value.

$$TOF = T_r - T_t \tag{1}$$

The distance between the localizer and an active beacon, d, can be obtained as the multiplication of v and the TOF.

$$d = v \cdot TOF \tag{2}$$

where the speed of the ultrasonic signal, v, is a function of the environmental temperature and is represented as

$$v \cong 331.5\sqrt{\frac{T}{237}}\ [m/s] \tag{3}$$

where T represents the absolute temperature [16].

When the absolute positions of the beacons are pre-specified as (x_a, y_a, z_a), (x_b, y_b, z_b), and (x_c, y_c, z_c), and the distances between the localizer and beacons are obtained as d1, d2 and d3, the absolute position of the mobile robot, $P(x, y, z)$, can be represented by the following equations.

$$\begin{bmatrix} (x-x_a)^2+(y-y_a)^2+(z-z_a)^2 \\ (x-x_b)^2+(y-y_b)^2+(z-z_b)^2 \\ (x-x_c)^2+(y-y_c)^2+(z-z_c)^2 \end{bmatrix} = \begin{bmatrix} d_a^2 \\ d_b^2 \\ d_c^2 \end{bmatrix} \tag{4}$$

From these equations, the absolute position of the mobile robot, $P(x, y, z)$, can be computed as

$$P = A^{-1}B$$

$$\text{where}\quad A = 2\begin{bmatrix} x_b-x_a & y_b-y_a & z_b-z_a \\ x_c-x_b & y_c-y_b & z_c-z_b \\ x_a-x_c & y_a-y_c & z_a-z_c \end{bmatrix},\ P = \begin{bmatrix} x \\ y \\ z \end{bmatrix}, \tag{5}$$

$$\text{and}\ B = \begin{bmatrix} d_a^2-d_b^2-x_a^2+x_b^2-y_a^2+y_b^2-z_a^2+z_b^2 \\ d_b^2-d_c^2-x_b^2+x_c^2-y_b^2+y_c^2-z_b^2+z_c^2 \\ d_c^2-d_a^2-x_c^2+x_a^2-y_c^2+y_a^2-z_c^2+z_a^2 \end{bmatrix}.$$

2.3 Multi-block Localization System

The localization of the mobile robot becomes extremely complex and difficult within a multi-block workspace, which has multiple beacons installed. A new multi-block localization system, based on the iGS, is proposed in this paper for the most precise localization of the mobile robot. Figure 3 shows the structure of the multi-block localization. Multi-block scheduling algorithm is implemented to select optimal beacons set. The RFID transmitter in the localizer sends trigger signals to activate the selected beacons. When the active beacon receives its own ID, it sends an ultrasonic signal back to the localizer on the mobile robot. The distance from the beacon to the mobile robot can be calculated by multiplying the TOF and travel speed of the ultrasonic signal. A sleep mode is also adopted for the active beacons, to save power while they are not in active use.

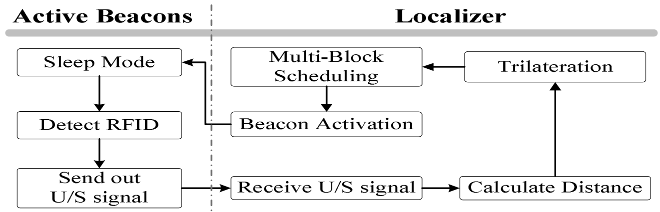

Fig. 3. The structure of the multi-block localization

3 Beacon Scheduling

Since the strength of ultrasonic signals decay by the inverse square of the distance from the source [17], one set of the iGS can only covers an area of about 5 m x 5 m (assuming that there are no obstacles in the room). When it is necessary to localize mobile robots globally, the overcoming of obstacles, as well as decay problems, needs to be also addressed. In these cases, the sensor space can be divided into multiple blocks to provide a solution for the global localization.

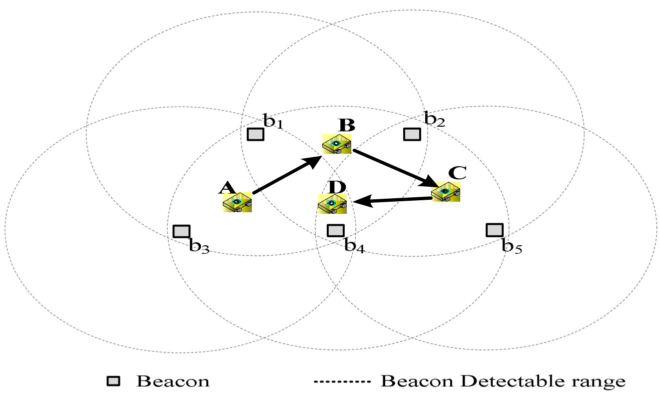

Fig. 4. The example of beacon scheduling

Since the performance of the trilateration is affected by the raging errors, by the geometrical arrangement of the beacons, and by the location of the mobile robot, it is necessary to select the optimal beacons to improve the localization accuracy in multiple blocks. As the beacon selecting method, one is to change the block and update the beacon information according to the robot position, and the other is to recognize the boundary between each block and to aware the new block. However, the case of above mentioned methods can cause the problem that the beacon information cannot be updated because of the block recognition failure at the boundary, or because beacons do not work well. Therefore, this paper proposes the efficient algorithm for adding new beacons or failure of block switching.

Beacon scheduling algorithm is based on the distance from the mobile robot to the beacon and geometrical arrangement of the beacons. In the case of iGS which uses threshold value, every beacon has the same detectable range. Three beacons at least are needed for localizing a mobile robot. Thus, it is possible to schedule beacons according to the position of the mobile robot if the mobile robot knows own position, position of beacons and beacon detectable range. Figure 4 shows the example of beacon scheduling.

When a mobile robot locates at A point, b_1, b_3 and b_4 are usable and the robot employs b_1, b_2 and b_4 after it moves into B point. And then, if the mobile robot moves to C point, it employs b_2, b_4 and b_5 to localize. Like the above case, it is possible to make the beacon schedule to select the usable beacons according to the position of the mobile robot. However, if the mobile robot moves to D point, b_1, b_2, b_3, b_4 and b_5 are able to obtain the distance data from every beacon. Since three distance data are needed for trilateration, the mobile robot should select three of five beacons because the more beacons it uses, the much time it needs. To select optimal beacon set, the DOP analysis [9] is adopted to determine which beacons can be used.

GDOP values are calculated from the positions of the mobile robot and usable beacons set. The best reliable beacons set have the lowest GDOP value and the beacon schedule uses it. At D point in Fig. 4, b_1, b_3 and b_5 beacons set or b_2, b_3 and b_5 beacons set have the lowest GDOP value. If there are GDOP values to be equal, a low beacon ID number has a priority. Therefore, b_1, b_3 and b_5 should be called at D point. Figure 5 shows beacon schedule with selected beacons set while it moves from A to D and Fig. 6 summarizes the beacon scheduling algorithm developed.

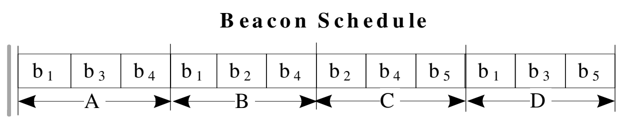

Fig. 5. Beacon Schedule

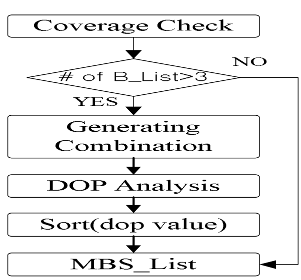

Fig. 6. Beacon scheduling algorithm

Coverage check is to make beacon list, B_List, which the mobile robot is able to utilize beacons which are obtained by using the position of the mobile robot and coverage of beacons. If there are more than three beacons, generating combination is carried out for making the combination of beacons set, which consist of three beacons. DOP Analysis is produced for calculating DOP values of the beacon combination. And then B_List is sorted in ascending order of DOP values. Finally, beacon schedule list, MBS_List, which has the optimal usable beacons set geometrically, is returned for precise localization.

4 Experiments

The mobile robot used in this paper is developed with DC motors having embedded encoders and the dsPIC30F4012 from Microchip for the control. The experimental iGS is composed of the localizer on the mobile robot and the beacons on the wall or ceiling shown. The localizer system uses the TMS320C2406A from TI for the system control, the rfPIC12F675F from Microchip for the RF signal control, and the AT40-10P (40 kHz) from Nippon Ceramic for the ultrasonic signal receiver. The beacon system uses the MSP403F1101A from TI for the system control and the AR40-10P (40 kHz) for the ultrasonic signal transmission. Estimating distance from beacon to receiver takes 43ms per a beacon and the average error in measuring the distance is 2.3mm. The experiments are implemented indoor environment, where eight beacons are deployed in the workspace by the vertex of (x, y, z)[unit : mm] with the mobile robot, to prove the algorithms in this paper. The monitoring programs for the user were developed on a PC using Visual C++ 6.0 which enables the real time monitoring of the robot motion on the two dimensional map. Figure 7 and Fig. 8 shows the experimental environments used in experiments.

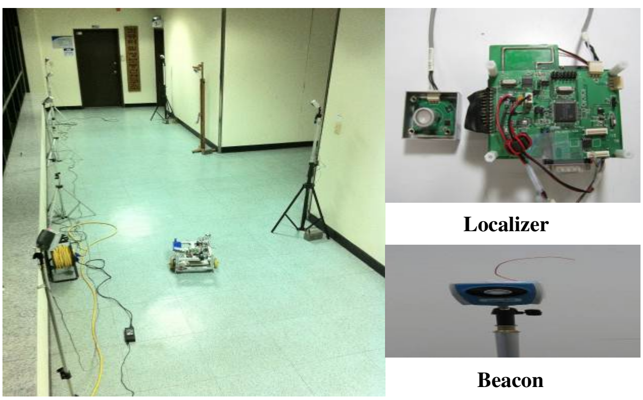

Fig. 7. The experimental environment

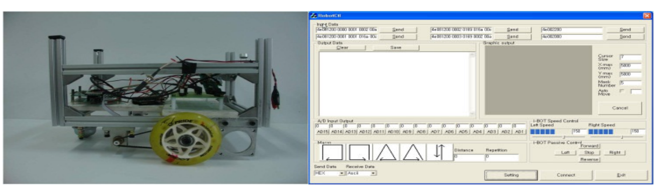

Fig. 8. The mobile robot and monitoring program

Figure 9 shows the deployment of the beacons and the route of the mobile robot. Eight beacons are deployed in the workspace with the mobile robot moving from point A to Point D.

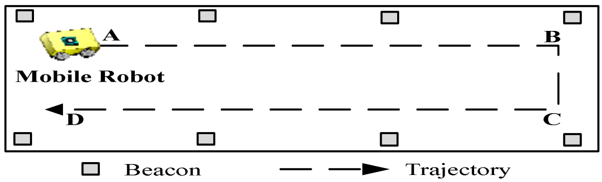

Fig. 9. The deployment of the beacons and the route of the mobile robot

Two different experiments are carried out to demonstrate the performance of the multi-block application and compare the trajectory of the mobile robot. Experiment 1, as shown in Fig. 10, uses the conventional multi-block system which beacon information is updated by using block switching algorithm at block boundary. The navigation result is seen to have different levels of error when the beacons change, because the system selected certain beacons without choosing the optimal beacons according to the positions of the mobile robot and beacons. As a result, there were several gaps in the route of the mobile robot when the block and the beacons are changing.

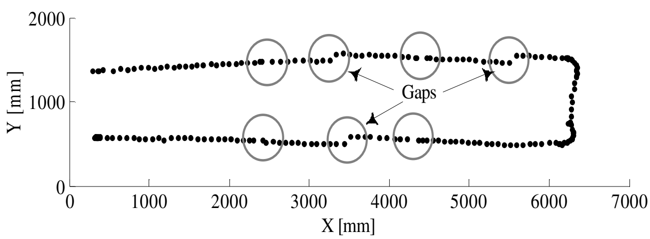

Fig. 10. Result of the navigation with the conventional multi-block system

Experiment 2 uses beacon scheduling algorithm proposed in this paper. Figure 11 illustrates the trajectory of the mobile robot. The system obtains a smoother trajectory for the mobile robot without route gaps than experiment 1, since the optimal beacons were selected from the positions of the robot and beacons.

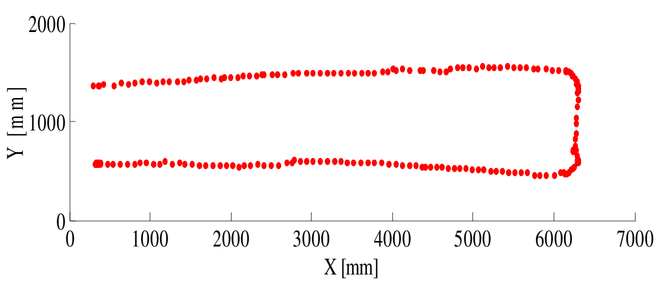

Fig. 11. Result of the navigation with the beacon scheduling algorithm

5 Conclusions

The ultrasonic sensor based localization system has been widely used since it is cheap, accurate and easy to control in indoor localization. However, on account of their decay phenomena when they are transmitted over a long distance, ultrasonic sensors are not suitable for application in large indoor environments. In this paper, to overcome these shortages of ultrasonic sensors while emphasizing their advantages, a new approach with multiple beacons has been proposed. For the real time localization of mobile robot, beacon scheduling algorithm without effecting beacons placement has been developed. The effectiveness of the localization system is verified through real experiments of mobile robot navigation. This localization system can be applied for the location based service in a various field as well as robot position system.

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