Localization of multiple robots in a wide workspace

J.H. Park, W.S. Jang and J.M. Lee

Dept. of Electrical engineering, Pusan National University, Korea
(Tel : +82-51-510-1696; Fax :+82-51-514-1693)
(jae-hyun@pusan.ac.kr, masura0727@pusan.ac.kr, jmlee@pusan.ac.kr)

Abstract: This paper proposes a localization method for the multiple robots navigation in a multi-block workspace. Indoor localization schemes using ultrasonic sensors have been widely studied due to its cheap price and high accuracy. However, ultrasonic sensors have some shortages of short transmission range and interferences with other ultrasonic signals. In order to use multiple robots in wide workspace concurrently, it is necessary to resolve the interference problem among the multiple robots. This paper introduces an indoor localization system for concurrent multiple robots in a wide service area which is divided into multi-block for the reliable sensor operation. A beacon scheduling algorithm is developed to avoid the signal interferences and to achieve efficient localization with high accuracy and short sampling time.

Keywords: Localization, Multiple robots, Multi-block, Beacon scheduling, Block recognition.

I. INTRODUCTION

In order to perform the commands of humans, robots have to know their own positions and target position. For that reason, localization is one of the problems which are basic and important in robotics. Ultrasonic based localization is susceptible to environmental noises from their propagation characteristics and has decay phenomena when it is transmitted over a long distance. However, it has been widely used in the indoor environments since it is cheap, easy to be controlled and has high accuracy and repeatability. To use it in a wide area, multi-block consisted by a number of beacons is mainly used [1]. However, multiple robots localization in multi-block has some problems which are ultrasonic signal interferences and determination of sequence calling beacons [2]. This paper proposes efficient multi-block division for multiple robot localization in a wide area using Master/Slave robot division for beacon arbitration of robots and beacon scheduling algorithm for calling beacon without interference in ultrasonic signal with short sampling time.

II. MULTIPLE ROBOTS LOCALIZATION

1. **Problems Definition**

If there are more than two mobile robots in a same workspace, where consists of three or four beacons, they separately call different beacons for localization concurrently. And then all selected beacons send out ultrasonic signals at once. At this time, mobile robots cannot recognize which beacons send out a useful signal from beacon themselves called since TOF of ultrasonic from beacons is different and the robots recognizes a threshold value of the first arrival signal. Therefore, the robots do not know their own real positions due to measurement of wrong distance.

2. Master/Slave Robot

Only one robot is designated as the master robot and the other robots are designated as the slave robots. Master robot has a mission to call the specified beacon only and Slave robots respectively receive the ultrasonic signal from a specified beacon calling the master robot. The master robot considers max transmission time of ultrasonic because the arrival times of ultrasonic signal are different according to positions of the robots.

III. BEACON SCHEDULING

1. Beacon Scheduling

For localization without signal interference in a multi-block workspace which is divided in a detectable range, a round robin schedule is one of the simple methods. However, the round robin schedule is not suitable in a real time localization system which updates each position of robots in a fast period due to increasing a time to call all beacons as increasing the number of beacons. For that reason, efficient beacon scheduling algorithm needs to obtain the fast period for localization in a multi-block workspace. This paper proposes a new beacon scheduling algorithm applied a color code scheduling algorithm.

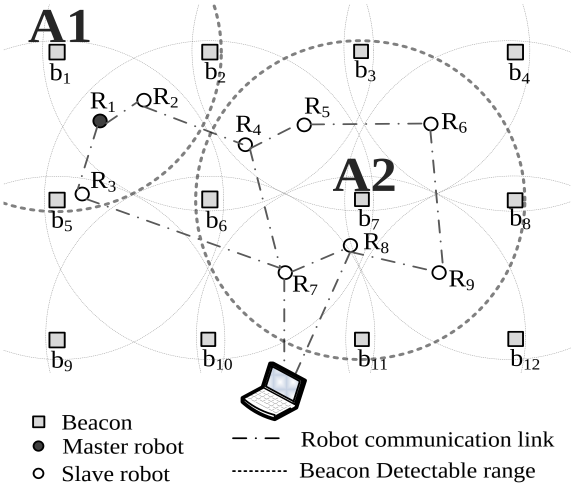
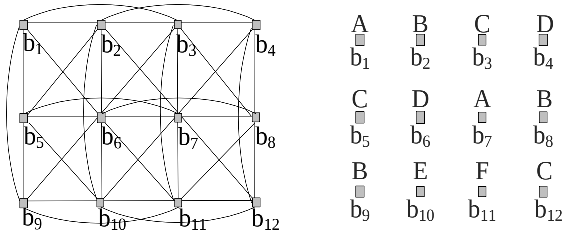


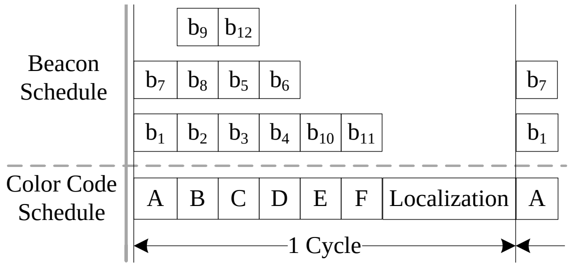
Fig.1. Basic structure of multiple robot localization in a multi-block workspace

2. Color Code Scheduling

Color code scheduling is the method that concurrently calls beacons without collision among signals based on the idea that ultrasonic signal does not collide out of their interference range. Color code scheduling is divided into three steps which are conflict graph, graph coloring and scheduling [2]. The first step is to draw a conflict graph considering beacon's position and ultrasonic interference range from the beacon. For example, b1 beacon in Fig. 2 is connected with b2, b5, b6 and b9 beacons with edge in Fig. 2-(a) because of overlapping the interference ranges shown in Fig. 1. With conflict graph about all beacons, the second step is to assign a color code to each beacon such that any two beacons with a conflict edge cannot have the same color. This paper uses a Welsh-Powell algorithm [4] to find the coloring solution with the chromatin number. Figure 2-(b) shows graph coloring with conflict graph in Fig. 2-(a). Finally, the third step is to make a color code schedule which is designated by different color codes in Fig 2-(c).



(a) Conflict graph (b) Graph coloring



(c) Color code schedule

Fig.2. Color code beacon scheduling

3. New Color Code Beacon Scheduling

The conventional color code scheduling is able to concurrently call two beacons which never overlap the interference ranges. But, in case of ultrasonic localization system using threshold value, ultrasonic signal from the closed beacon always arrives firstly. In a multi-block workspace, therefore, some cases that are able to concurrently call beacons which overlap the interference ranges exist. For example in Fig. 3, a b1 beacon belong to block 1 overlaps the interference range of a b3 and b6 belong to block 2 only not to block 1. If b1 and b2 beacons concurrently call, R1 robot existed in the interference range of them always receives the ultrasonic signal from a b1 firstly. Hence, concurrently calling them will be possible. Considering the abovementioned problems, algorithm to draw a new conflict graph represents in Fig. 4.

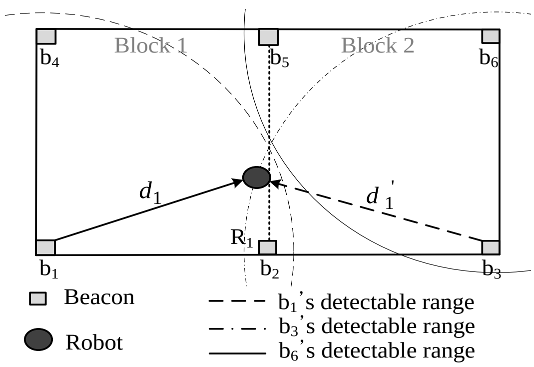


Fig.3. New conflict graph algorithm

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Input : Coverage of each beacon C(bi) ( 1<= I <= Nb)
Output : conflict graph CG(Vb, E)
1.    For each beacon i = 0, …, Nb
2.       For beacon i+1,…, Nb
3.          If ((C(bi) ∩ C(bi+1)) > 0)
4.             If(beacon ID(bi+1)∈ block of beacon bi Block(bi)
5.                && C(bi+1) != diagonal C(bi))
6.                   CG[i][i+1] = 1;   // conflict
7.             else
8.                   CG[i][i+1] = 0;
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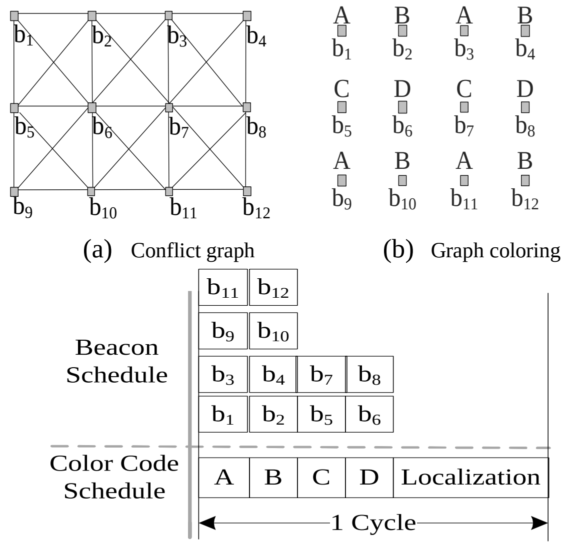
            End if
      else
            CG[i][i+1] = 0;
      End if
   End for
End for
```

Fig.4. New conflict graph algorithm

Figure 5 shows new color code beacons scheduling allows some interference with the position and the interference range of all beacons shown in Fig. 1.



(c) Color code schedule

Fig.5. New color code beacon scheduling

IV.BLOCK RECOGNITION

Existing block recognition method[1] for using new color code beacon scheduling can sometimes make problems that the robot estimates a wrong position shown in the Fig. 6. In case of color codes B and D, each range is overlapped, but it is assumed that it is possible to call them at the same time. When a robot is at P_{n-1} in block 1, it will receive the US signal from the b1 beacon firstly than b3 beacon if a beacon of color code B is called, and the robot will receive the US signals from b1 and b3 beacons at nearly same time if it moves to the boundary of a block, P_n. In case of existing methods, if the mobile robot is moving out of the boundary of block 1, it may recognize block 2 by using its own position. However, the mobile robot will be localized by using the position information of beacons in block 1 and $d'_i,(i=1,2,3,4)$, the same distance value with $d_i,(i=1,2,3,4)$ measured by P_{n+1} if the beacon scheduling algorithm suggested in this paper is used, because it can receive a signal from b3 beacon but it cannot recognize block 2 when it is moving from P_n to P_{n+1}. Hence, it will not measure P_{n+1} but P'_{n+1} which is wrong position of the robot. To solve this problem, this paper presents a new block recognition algorithm using a previous position value and a predicted position value obtained by motion characteristics of the robot at the boundary of blocks.

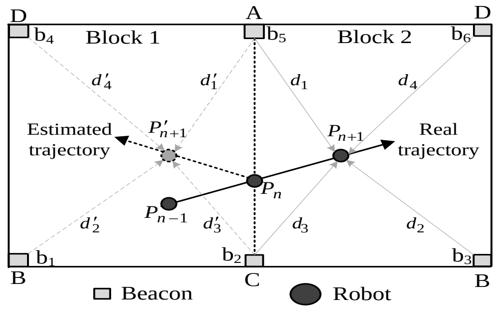


Fig.6. Error location estimation of mobile robot due to fault of block recognition

1. **Estimating the position of a robot**

Theoretically, it is possible to calculate them which are the angular velocity of the mobile robot, r_ω, the driving distance of the mobile robot, d and the rotation radius, R if the information of two past position $P_{n-1}=[x_{n-1}\ y_{n-1}\ \theta_{n-1}]^T$, $P_n=[x_n\ y_n\ \theta_n]^T$ are known [3]. Based upon the motion-continuity property, the state of the mobile robot at time $n+1$, $P_{n+1}=[x_{n+1}\ y_{n+1}\ \theta_{n+1}]^T$ can be predicted as [15]

$$\hat{x}_{n+1}=x_n+R\{\sin(\theta_n+\Delta\theta)-\sin(\theta_{n+1})\}, \tag{1-a}$$

$$\hat{y}_{n+1}=y_n+R\{\cos(\theta_n+\Delta\theta)-\cos(\theta_{n+1})\}, \tag{1-b}$$

$$\hat{\theta}_{n+1}=\theta_n+\Delta\theta. \tag{1-c}$$

This predicted location is used for the recognizing blocks.

2. Block recognition by using the predicted location

If the mobile robot is approaching near the boundary between block 1 and block 2(±10cm, considering the maximum error of iGS), it is able to calculate two new position coordinates of location $P_{block\ 1}$ and $P_{block\ 2}$ by using beacon information of each block and then, a new position coordinates is going to be a minimum value which is obtained between the predicted location, $\hat{P}_{n+1}$ from 2 previous locations and the measured location, $P_{block\ 1}$, $P_{block\ 2}$. If the robot goes through a beacon b6 in Fig. 1, it will be possible to recognize a new block by comparing between four beacons coordinates from four blocks and predicted coordinates.

V. EXPERIMENTS

For algorithm verification, four-block were built by 9 beacons with one master robot and two slave robots. Error comparative analysis method was used between the encoder trajectory and iGS moving trajectory of mobile robot.

Fig. 7 & 8 illustrate moving trajectory of three mobile robots in one workspace consists of several blocks and the estimated error for each robot, respectively. The average error of three mobile robots is 22.12mm and the maximum error is 67.62mm, which is accurate enough to apply to most of the mobile robot navigations using beacon scheduling algorithm and block recognition algorithm.

VI. CONCLUSION

Although ultrasonic localization system is not feasible for localization of multiple robots in multi-block environment because of attenuation and interference among ultrasonic sensors, it is widely used for indoor localization systems since it is cheap and easy to be controlled and also it has high accuracy and repeatability. This paper proposes a new color code beacon scheduling algorithm for the arbitration among robots. A new block recognition algorithm based on motion characteristics of the mobile robot is also proposed in this paper for recognition of block boundary when the mobile robot is moving freely in the multi-block environment. And also for the efficient localization of multiple robots, the master and slave concept is introduced to govern the localization process synchronously. The efficiency of localization algorithms proposed in this paper is verified through the real experiments for multiple robots' localization in a multi-block workspace. Through this research, the base of the localization-based services is established since this localization scheme is robust against increase of the number of robots and the size of indoor environments.

ACKNOWLEDGMENT

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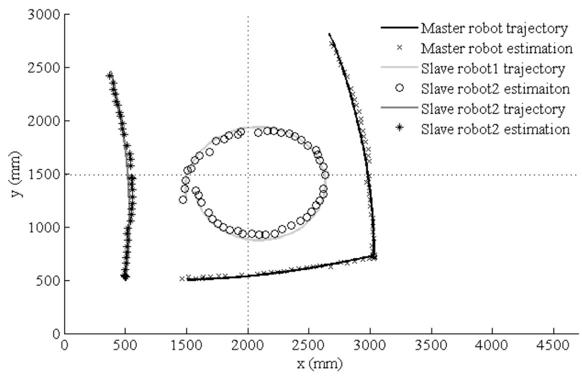

Fig.7. Trajectory of three robots in four-block

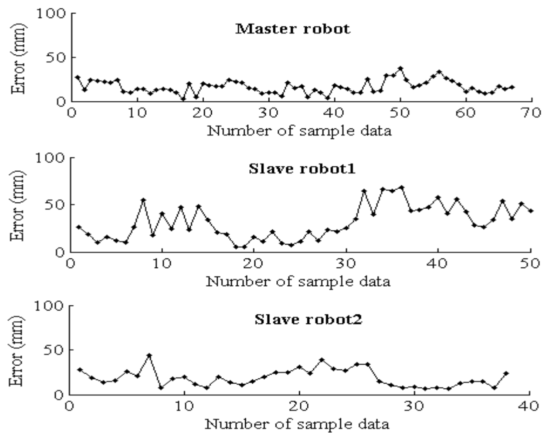

Fig.8. Estimated position error according to the number of sampled data