An Indoor Localization System for Mobile Robots Using an Active Infrared Positioning Sensor

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***Abstract*—Infrared (IR) sensors have been widely used as a distance measuring sensors to estimate the position of an object since they have short response time and high accuracy. Therefore, we introduce the indoor localization system using an active infrared sensor and passive landmarks. However, there were several types of deviations from the actual values. We analyzed these errors and corrected them to develop the improved localization system.**

***Index Terms*—infrared sensor, artificial landmark, multi-robot, indoor localization, intelligent space**

I. Introduction

Indoor positioning systems have become important in recent years [1], as modern people spend a large amount of their time indoors. These systems have been successfully used in many applications, such as security robots and cleaning robots. Therefore, there are several kinds of indoor localization systems with different architectures to estimate the positions of mobile robots, such as: Active Badges [2], RADAR [3], Smart Floor [4], and Radio tags [5]. These systems use various sensors like ultrasound, radio signal, and light. Among the sensors, infrared (IR) sensors have many advantages like short response time and high accuracy [6]. Therefore, we develop the system using IR sensors to build the indoor localization system.

This paper is organized as follows. Section II explains the basic properties of the IR sensor, especially, the StarGazer of HagiSonic(Fig. 1 (a)) which we used in this paper and explanations about the localization process.

Figure 1. (a) The IR Sensor, (b) Passive Landmark

Organizing a global coordinate system using this sensor is also discussed in the section. Section III evaluates this system and analyzes the error between sensor values and actual values. We categorized these errors into three types of problems. In section IV, we introduce the ways to solve these problems above and corrected the problems to develop the improved system. The experimental result of the proposed system is given in section V and finally this paper is concluded in section VI.

II. System Modeling

A. The IR Sensor and Positioning Process

Fig. 1 (a) is the StarGazer of Hagisonic [7]. It is an active positioning sensor relied on the deployment of passive landmark (Fig. 1 (b)) mounted on the ceiling. The specification of the sensor is in Table I.

Fig.2 explains how the sensor finds the location of itself. The sensor emits IR light which is reflected by passive landmarks with an independent ID. Then, an IR sensitive camera observes the reflected light and analyzes IR ray images to determine the relative position of the sensor from the landmark. Organizing a Global Coordinate System

TABLE I. Specification of the StarGazer

Size	50×50×28 mm
Measurement Time	10times/sec
Range(per a landmark)	1.2~1.5m in radius (for ceiling height 2.4m)
Repetitive Precision	2 cm
Heading angle Resolution	1.0 degree
Power Consumption	5V : 300mA, 12V : 70mA

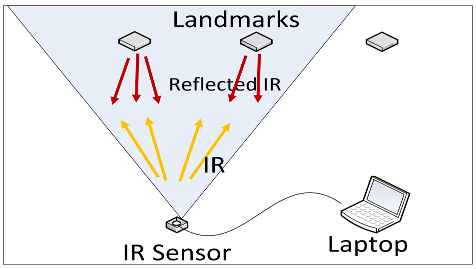

Figure 2. Localization process

B. Organizing a Global Coordinate System

The sensing range of each landmark is about 1.2~1.5m radius when the height of the landmark is 2.5m [7]. We have to arrange the landmarks to find the global coordinate of the sensor when the size of the room is larger than this coverage. The IR sensor can obtain the relative position and bearing from each landmark. Therefore, if we know the absolute location of each landmark in global coordinate, we can have the global sensor location by adding these values. Therefore, the sensor can calculate

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the location from each landmark. If the sensor receives the data from several landmarks, the location is estimated by averaging these values.

III. System Evaluation and Problem Formulation

Even if we obtain the global location of the sensor using the procedure above, there are a few problems between an actual value and the sensor value. We analyzed these errors into three types of problems.

A. *Uncertainty Problem as Distance Increases*

The uncertainty of the sensor value increases as the distance between the landmark and the sensor increases [8]. This is the general problem of distance sensors. We collected 90 points of the data in sensor coverage. As depicted in Fig. 3, error, variance of x, and variance of y increases as the distance from the landmark grows. This means if the sensor is far away from the landmark, the collected data will be the unreliable data. Therefore, we cannot assume estimate the actual location of the sensor.

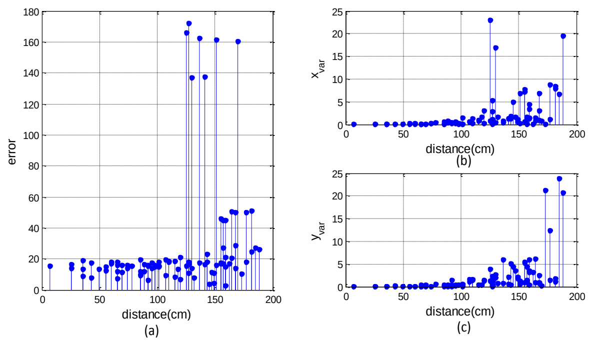

Figure 3. Distances versus (a) Error, (b) Variance of x, (c) Variance of y

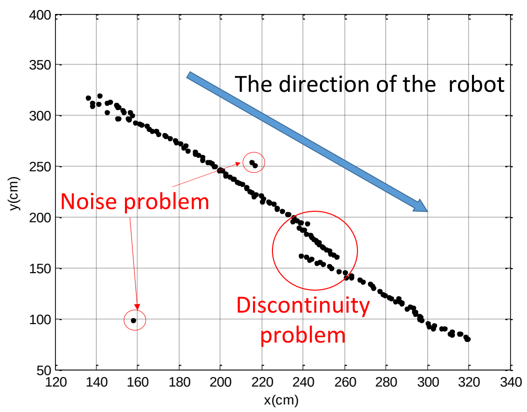

Figure 4. Discontinuity problems and noise problems

B. *Discontinuity Problem*

Discontinuity problems occurred as shown in Fig 4. The positioning sensor moved along the straight line in this figure. However, the result was not the straight line, but there was some discontinuous section in this figure. This is because of the changing of detected landmarks. As the landmark coverage is limited, the detected landmark will keep changing when the sensor moves from one place to another place. The data from each detected landmark should be interpreted as the same location in ideal case. However, the result from newly detected landmark is different from the existing data. Therefore, the trajectory shows the discontinuity problem occurs when detected landmark is changed.

TABLE II. The Ratio of Misidentification and Failure of Landmark

	Total	Misidentification	Failure
Sample running 1	1192	29(2.43%)	20(1.68%)
Sample running 2	1091	11(1.01%)	67(6.14%)
Sample running 3	1115	20(1.79%)	52(4.66%)
Sample running 4	1146	70(6.11%)	44(3.84%)
Sample running 5	1146	68(5.93%)	37(3.23%)

C. *Noise Problem*

The specification of the sensor we used implements the repetitive precision is about 2cm. However, in actual test, there were some noises as depicted in Fig. 4. The reason is the misidentification of the landmark or the failure of detecting the landmark. The sensor determines the relative position from the landmark. Therefore, if the landmark identification was misunderstood, the result would become inordinate values. The failure of detecting the landmark also gives the unreliable data and this makes the data hard to understand. We run sample experiments to check the ratio of misidentification and failure of landmark in the Table II. About 5~10% of the sample data have these problems, therefore, these untrustworthy data make hard to estimate actual location of the sensor.

IV. Improved Localization System

We discussed the problems of the localization system in section III. To solve these problems, we introduce the two solutions to improve the localization system. The solutions are the appropriate arrangement of landmarks and error correction algorithm.

A. *Appropriate Arrangement of Landmarks*

We analyzed the error is increased as the distance between the sensor and the landmark is increased in section III A, therefore, we can reduce error by densely placing landmarks. However, this can cause the changing of detected landmarks more frequently, so the discontinuity problem occurs more than before.

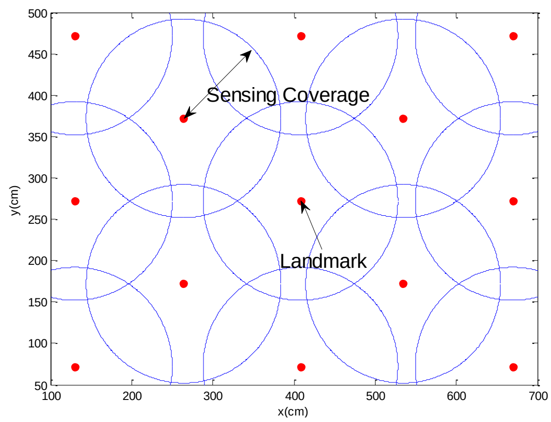

Figure 5. Appropriate arrangement of landmarks

Thus, the distance between landmarks is the crucial problem to reduce the errors, and we found the appropriate interval is about 80% of the landmark height by experiments. When the landmark height is 2.5 m, the sensor radius is 1~1.2m, so about 13 landmarks is the solution in the space of 7 × 5m as depicted in Fig. 5.

B. Error Correction Algorithms

We apply an adaptive extended Kalman filter (AEKF) to estimate the position of robots [9] equipped with an IR camera. The data provided by wheel encoder of the robot and IR sensors are fused together by means of EKF. To be specific, denote with $\mathbf{x}_k := [x(k), y(k), \theta(k)]^T$ the robot state which is obtained from the IR localization sensor and $\mathbf{u}_k := [\Delta s_r(k), \Delta s_l(k)]^T$ the robot control input. The system is described by the nonlinear model

$$\mathbf{x}_k = f(\mathbf{x}_{k-1}, \mathbf{u}_{k-1}, \mathbf{w}_{k-1}) \qquad \mathbf{z}_k = h(\mathbf{x}_k, \mathbf{v}_k) \tag{1}$$

where $\mathbf{w}_k$ and $\mathbf{v}_k$ are the process and observation noises which are assumed to be zero mean multivariate Gaussian noises with covariance $\mathbf{Q}_k$ and $\mathbf{R}_k$, respectively and $\mathbf{z}_k$ is the odometer measures. Then, the performance of the filter can be degraded according to the noise statistics. We have to adjust these statistics according to the environment and data we got from the sensor. Therefore, the AEKF here proposed can adaptively estimate the correct locations even if we got the poor sensor values. Measures are discharged if the difference exceeds a threshold. The structure of the proposed localization algorithm is reported in Fig. 6.

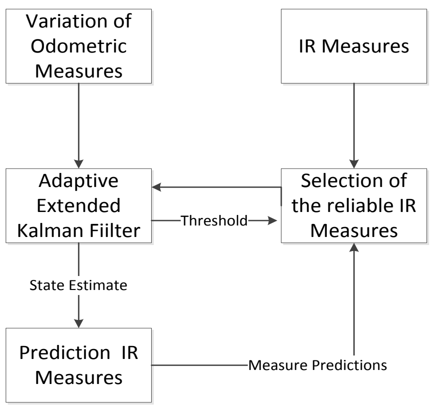

Figure 6. Estimation algorithms using AEKF

V. EXPERIMENTS

The experiments are performed to validate our algorithms in an indoor environment. Pioneer-3DX equipped with StarGazer is used to obtain the data and experiments are carried out in Automation and System Research Institute (ASRI), Seoul National University.

Fig. 7 shows the trajectory of our experiments. Fig. 7 (a) shows sensing data of IR and odometer measures. The results show sparse and noisy data which have discontinuity problems and noise problems in both experiments. The encoder data were similar to IR data at first, however, the difference between them gradually increases (Fig. 8).

However, Fig. 7 (b) shows the improved estimation of the trajectory of robot. The driving path of the robot shows smooth and clear line. Therefore, it is possible to know that we developed the robust and improved localization system using the conventional IR sensor.

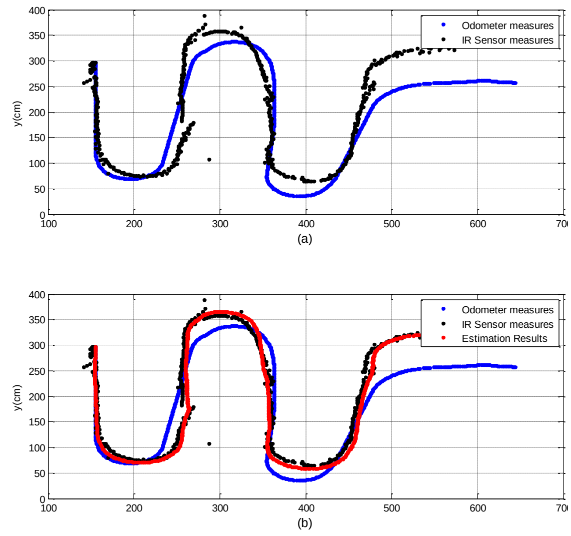

Figure 7. Experiment 1 (a) IR sensor and wheel encoder measures (b) Estimation results

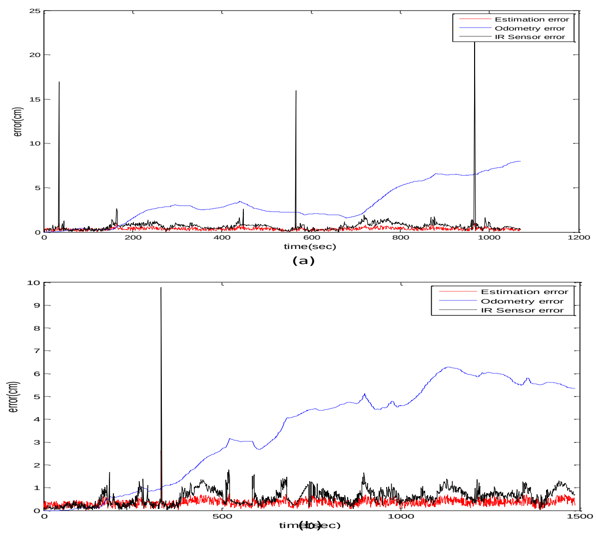

Figure 8. Time versus different kinds of errors (a)Experiment1 (b)Experiment2

TABLE III. ERROR ANALYSIS OF EXPERIMENTS

Experiment1			
Units(cm)	Mean	Variance	Max
Odometer Error	3.2155	4.9956	8.0213
IR Sensor Error	0.6794	0.9912	21.5870
Improved system Error	0.3545	0.0219	1.0532
Experiment2			
Odometer Error	3.4974	4.4142	6.2871
IR Sensor Error	0.6052	0.2209	9.7885
Improved system Error	0.3471	0.0274	2.7832

Details are depicted in Table III, IR sensors have high precision than odometer measures. However, they often have high peak of errors and this makes the localization quality poor. Using our algorithm, we can lower the differences between the estimation location and the actual place of robots.

VI. Conclusion

We have presented the indoor localization system using an active infrared sensor. The uncertainty increases as the distance from the landmark and there were several types of errors like uncertainty problems as distance increases, discontinuity problems and noise problems. We analyzed them and developed using optimal arrangement of landmarks and AEKF. As a result, we developed a significant improvement in localization system.

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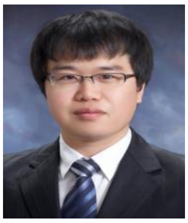

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