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Simultaneous Localization and Mapping of Wheel based Autonomous Vehicle with Ultrasonic Sensors

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Abstract: Autonomous localization and mapping requires a vehicle to start in an unknown location in an unknown environment and then to incrementally build a map of landmarks present in this environment while simultaneously using this map to compute absolute vehicle location. The theoretical basis of the solution to this problem, known as Simultaneous Localization and Mapping (SLAM), is now well understood. A number of approaches to SLAM have appeared in the recent literature. In this paper, we used ultrasonic sensors and digital magnetic compass for measuring range, and used gyro sensors and encoder for positioning. Fusing ultrasonic sensor and digital magnetic compass have advantages of both economical efficiency and complementary cooperation. Experimental results show that the SLAM algorithm can successfully be executed with high accuracy and reliability.

Keywords: SLAM, Autonomous Vehicle, Ultrasonic sensor, Digital magnetic compass.

I. INTRODUCTION

The currently robot is applied to the fields and objectives more various than the previous robot that wrought simple and recursive work, so it is required to become the intelligent robot that will able to judge and move by itself. To be such intelligent robot need to be consisted of localization technique, path planning technique, map building technique for multi robot. Localization and map building is base technique among to the techniques, those are being studied actively. In the recent years, Technique that integrated localization and map building is named simultaneous localization and mapping (SLAM). This technique can improve the performance of localization using map information that is made by map building technique.

First of all, let us look about map building or map mapping. Those are being studied actively using distance sensors that are laser range finder, vision sensor, Infrared sensor, ultrasonic sensor and etc. [1] Each of sensors has merits and demerits. Laser range finder has very high accuracy, but it is very expensive and has a high electric power than other sensors. In case of vision sensor, can have plenty of environment information, but it have problems that have to operate plenty of data and have an accuracy that is very variable. Infrared sensor is cheap, but it can't guarantee high performance because its maximum range is less than 100cm. On the other hand, ultrasonic sensor is cheap, and can measure more than 300cm. [2] And we can expect high accuracy and credibility because that is strong on noise disturbance.

The sensors that used on localization technique are divided largely global positioning sensor and local positioning sensor. Most sensors for measuring global positioning are expensive, and have restriction on installation environment. On the other hand, sensors for local positioning, such as encoder, gyro, electric compass, and etc. are very cheap and strong on noise disturbance than global positioning sensors. However, those can't calculate the position in absolute coordinate, and have a problem that error is accumulated. In this paper, we aim to find position of robot in absolute coordinate using ultrasonic sensor and encoder, gyro, electric compass.

This paper is consisted as follows. First of all, we present a system configuration of autonomous vehicle in section 2, and techniques related SLAM used in this

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paper. Finally, we describe experiments and results in section 4.

II. Autonomous Vehicle

1. Measurement System

The Objective of this paper is SLAM technique using five ultrasonic sensor and two encoders, gyro, electric compass. We designed and made an actual autonomous vehicle. The driving part of this vehicle is based on 2 wheels - drive which has linearly 2 - degree of freedom. Fig.1 shows that system configuration of autonomous vehicle. As shown in Fig.1 we used various sensors, such as ultrasonic range finder and encoder, gyro, electric compass which specification of each sensor shown in Table 1. Electric compass data usually affected by magnetic field of own motor. So we used gyro that has high accuracy during vehicle is moving, and electric compass when vehicle is stopped. In this way, we could calculate more accurate orientation angle data for implement SLAM.

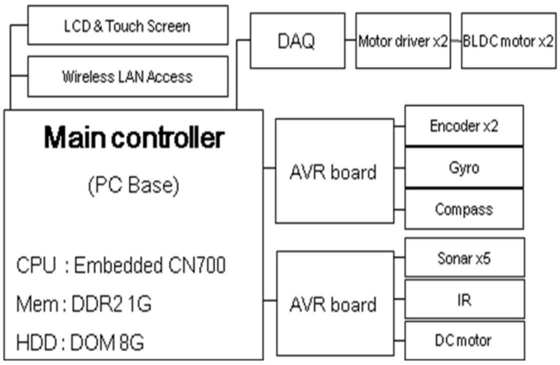


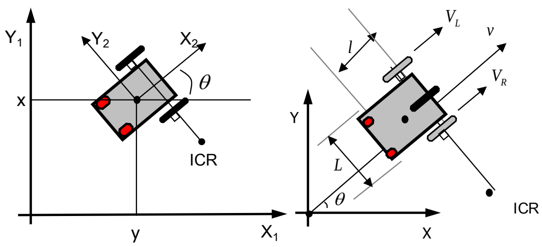
Fig.1. System configuration of autonomous vehicle

Table 1. Specification of sensors used

Item	Specification	
Ultrasonic(SRF04)	Frequency	40kHz
	Range	300~3cm
Encoder(MD200)	Voltage	5V
	R-F Time	300us
Gyro(ADXRS401EB)	Voltage	5V
	Sensitivity	±75 ˚/s
Compass(CMPS03)	Resolution	0.1 ˚
	Accuracy	3~4 ˚ approx.

2. Kinematics

This section will analyze the kinematics of vehicle to calculate the own position. Fig.2 shows kinematics of vehicle. X1-Y1 axis is the absolute coordinate, and X2-Y2 axis is the relative coordinate based on vehicle own position and X2 axis is vehicle's forward moving direction.



a. Coordinate of robot b. Bicycle model

Fig.2. Kinematics of autonomous vehicle

$$P = (x, y, \theta)^T \tag{1}$$

P is definition of vehicle's posture. The x, y is coordinate of vehicle, θ is the angle of moving direction. Driving model can represented by bicycle model as shown in Fig.2b. If angular velocity of both wheels are ω_R, ω_L and radius of wheel is r then linear velocity of each wheels are as follows.

$$V_R = r\omega_R \ , \quad V_L = r\omega_L \tag{2}$$

If distance between both wheels are L, then the angular velocity(ω) and linear velocity(v) of vehicle based on absolute coordinate (X1-X2) are related with kinematics on two-dimensional coordinate system. Also those are represented by equation (3).

$$\begin{aligned} \omega &= \frac{V_R - V_L}{L} = \frac{r}{L} \\ v &= \frac{V_R + V_L}{2} = r\omega \end{aligned} \tag{3}$$

So we can calculate the posture vector (P) from linear and angular velocity by equation (4).

$$P = \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix} \tag{4}$$

3. Driving Control

To control driving of vehicle safely, we used fuzzy logic control in -50° ~ +50° section and proportional control in rest of section. (Fig.3)

In case of fuzzy logic control, there is a problem that caused by a plenty of calculation. Thus, we defined membership functions using fuzzy toolbox of MATLAB R2008, and made a lookup table. Main controller loads the lookup table then control the vehicle, so it works well in real-time.

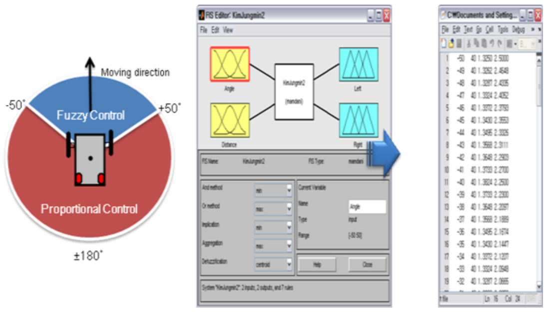


Fig.3. Driving control of autonomous vehicle

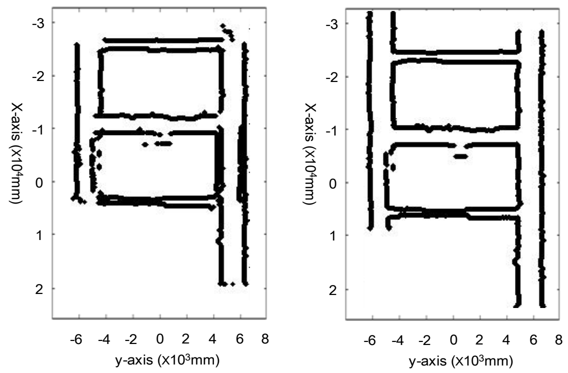
III. Simultaneous Localization and Mapping

1. Map Building

Map building must be leaded before implementation of the SLAM, and the performance depending on the accuracy of map building. In general, the map can represent by Grid and Topological, Feature, Hybrid type. Moreover, there are two main map building methods that standard map building and hierarchical map building. [3] Fig.4 compares standard map building and hierarchical map building method by Grid type.

We use two distance variations that measured by ultrasonic range sensor of autonomous vehicle. Global map is consist of every points that moved and measured by vehicle, so this map has duplicated points.(Fig.4a) Also accumulated error of encoder and gyro cause localization error of the entire map. Actually, if vehicle moves 180 meters, then orientation and distance error was about to 6°(degree) and 20 cm. On the other hand topological map is more precise than global map as shown in Fig 4b. t But if the map represented by grid type, system require a very large storage space and real time calculations may be difficult. So, in his paper we represent hierarchical map by feature type. [4]

Fig.5 shows map building by extracted and clustered feature points. The red spots on the top and bottom of the horizontal direction show that the doors of the seminar rooms and lab, and spots on the horizontal direction show lockers and elevators, mirrors, stairs.



a. General map　　b. Topological map

Fig.4. Map Building Method

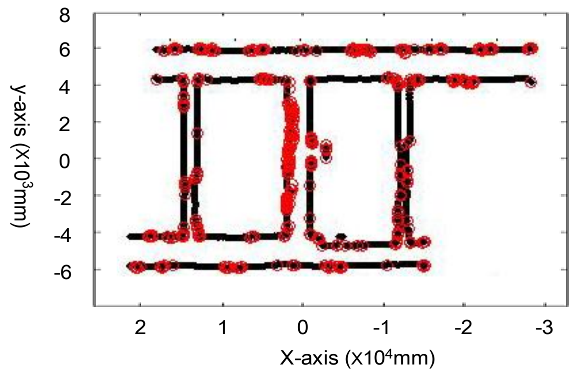


Fig.5. Feature points on the map

2. SLAM

Typically, localization using only gyro and encoder can calculate relative coordinates based on the start position of vehicle. However, absolute position must be known if vehicle want to go to goal position. SLAM algorithm that calculate the absolute position of vehicle in unknown location is as follows flow chart.(Fig.6) First, vehicle that starts in unknown location calculate the orientation of itself by using electronic compass. And calculate the relative angle base on own corridor using distances of ultrasonic range sensors and compass orientation angle. [5] Then vehicle move to the center of the corridor by measured distance, and move through the wall of corridor. Simultaneously compare with feature points that are measured by vehicle and map building features, and calculate the absolute location of vehicle. Our designed vehicle will move to the center of corridor continuously if there are no obstacles. This algorithm is not only calculate absolute position, but how can reduce the error of position during vehicle is moving.

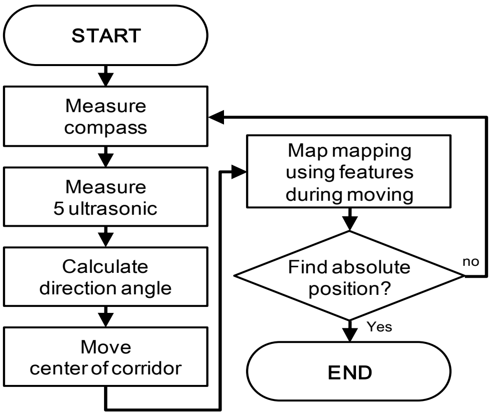


Fig.6. SLAM algorithm

IV. Result

Fig.7 shows autonomous vehicle experimented. Development environment of this autonomous vehicle is Borland C++ 6.0 Builder and Code Vision AVR studio in Window XP. Experiment was performed after map building was done. (vehicle can find out 105 feature points as shown in Fig.5) Then, vehicle located in eight unknown location that is shown in Fig.8. Fig.9 shows measured during time and distance that vehicle was driven, used feature points. Actually in the ⓓ and ⓗ location, it took very long time because extracted map feature was not exactly.

Fig.7. Autonomous Vehicle

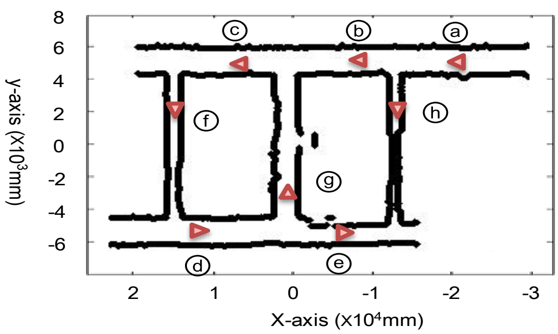


Fig.8. Unknown location at experiment

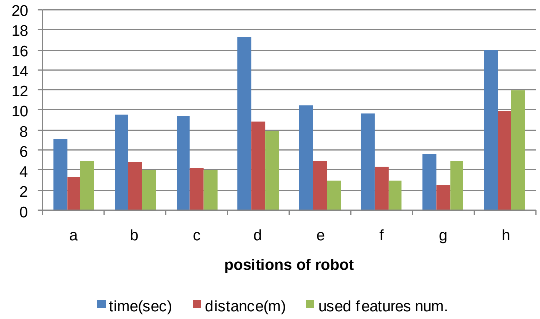


Fig.9. The result of experiment

V. Conclusion

In this paper, we were implemented SLAM using ultrasonic range sensors and encoder, gyro, electric compass. Map building as the previous step of SLAM made by distance variation of ultrasonic range sensor and map was constructed in hierarchical. Then extract feature point from map data. In experiment, vehicle can find out its absolute coordinate in average 10.7s (use five feature points, driving distance is about 5.39m) Applied to the real autonomous vehicle, finding absolute localization in real-time was able to see.

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