Development of an autonomous mobile robot:

Self-Localization and Mapping using Odometry and a Laser Range Sensor

Keisuke Niimoto

Graduate School of Computer Science
and System Engineering
Kyushu Institute of Technology
680-4, Iizuka City, Fukuoka, Japan, 820-8502
niimoto@imcs.mse.kyutech.ac.jp

Eiji Hayashi

Department of Mechanical Information
Science and Technology
Kyushu Institute of Technology
680-4, Iizuka City, Fukuoka, Japan, 820-8502
haya@mse.kyutech.ac.jp

Abstract

We are attempting to develop an autonomous mobile robot that has the ability to perform practical tasks in a human living environment by using information derived from sensors and a knowledge database. When a robot is made to adjust to a human environment, robots require systems that can recognize the external world and perform correct driving control. We have developed a self-localization method for an autonomous robot.

Odometori offers a self-localization method that is of the greatest use, providing a method of calculating and determining the tracks of a robot. However, there is a limit to the accuracy of this self-localization because a cumulative error occurs regarding the self-position determined by Odometori. To solve this problem, this paper describes the development of a self-localization method based on a fusion of Odometori and LRS (Laser Range Sensor) data.

Key words: autonomous mobile robot, LRS (Laser Range Sensor), Odometori, ICP (Iterative Closest Point) algorithm, Self localization, mapping.

1. Introduction

In our country now, the population is aging, and the number of people who receive nursing in hospitals and welfare facilities is increasing. At the same time, the proportion of the working population continues to decrease. Robots are expected to make a contribution in helping to solve the problem of the labor shortage this is creating. Indoor robots intended for use in a general life environment include, among others, cleaning robots, house-sitting robots, and guard robots. Indoor mobile robots that have movement functions like these robots are expected to evolve.

Environmental recognition is required so that the robot may coexist among humans. An autonomous mobile robot requires map information regarding its range of action. This includes a grasp of the position where the robot is located on the map. By recognizing this environmental information, the robot can search for a route to its destination and can accurately reach the destination. Therefore, the robot’s knowledge of its position on the map is one of the important environmental recognitions that is required.

Odometori is the self-localization method that has been of the greatest use; it can calculate distances and determine the tracks of the robot. However, there is a limit to the accuracy of this self-localization because a cumulative error occurs regarding the calculated tracks by encoder data [1][2]. To solve this problem, we developed a self-localization method based on a fusion of Odometori and LRS (Laser Range Sensor) data.

In our research up to last year, in which the data obtained from the LRS made a straight line, self-position was determined by matching the robot with an already-known obstacle. However, the inability to establish a correspondence to obstacles other than by a straight line (because in this technique the LRS data required a straight line) meant that the robustness was low. In addition, there was the problem that it was necessary to give information about the obstacle to the database before the position of the robot could be determined. Therefore, in our new system the LRS data does not require a straight line. The earlier problems were solved using an ICP algorithm to match LRS data with the database. Moreover, by using this method, the robot becomes able to construct a map without being supplied with a map beforehand. We mounted this system on the robot in an indoor environment and conducted an experiment involving self-localization and mapping.

2. System Architecture

In this research, we used a mobile robot, Kitasap2, developed in our laboratory. Figure 1 shows the externals of Kitasap2. It is composed of three wheels; the two front wheels are independent drives, and the rear wheel uses a ball. An encoder is installed on the front wheel, and a LRS is installed in front of the bottom of the robot. The robot is equipped with a computer that controls all devices; lithium-ion batteries supply the electric power.

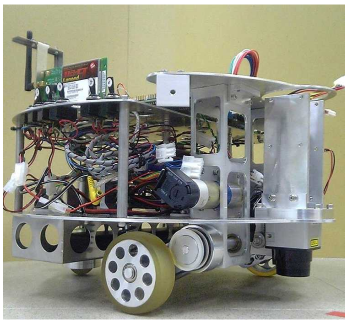


Fig. 1 Mobile robot

3. Self-Localization and Mapping

3.1 ICP algorithm

The ICP algorithm is a technique of the optimization of overlapping point sets [3]. For each point of point sets, the nearest point is looked for and related mutually. The least square method concerning the distance is calculated based on them (expression 1). And points are updated using a homogeneous transformation (expression 2). It then optimizes matching by repeating these procedures. The ICP algorithm has the following advantages. It is strong in suppressing noise; it need not be given correspondence points; it can be matched even if two sets of points are off to some degree; it does not require location information; and it can deal with overlapping of complex shapes. In this research, by applying this algorithm to match the LRS data with map information, the position of the robot is presumed.

$$F\left(Xg, Y\right) = \frac{1}{N}\sum_{i=1}^{N}\left|Xg_i^{(m)} - Y_i\right|^2 \qquad (1)$$

$$Xg_i^{(m+1)} = Trans^{(m)} + Rot^{(m)} \cdot X_i^{(m)} \qquad (2)$$

N ：Number of points
Xg_i ：LRS Data in global coordinates system
Y_i ：The map data of database
X_i ：Scanning data of LRS
Trans ：Translation procession
Rot ：Rotation procession

3.2 Self-localization method

The procedure for self-localization is shown below (See Figure 2).

Ⅰ. The rotation angle of the tire is acquired from the encoder. Tracks of the robot are calculated, and the position of the robot is presumed.
Ⅱ. Acquired data from LRS is transformed into a global coordinate system based on the self-position presumed from encoder.
Ⅲ. The map information (database) and the LRS data that transformed into a global coordinate system are compared. The nearest points are related mutually.
Ⅳ. The related point data is substituted for the evaluation function of the ICP algorithm (expression 1).
Ⅴ. If the value of the evaluation function is less than the threshold, it is considered to match. The value of the transformation matrix at that time is the position of the robot. (End)
If the value of the evaluation function is greater than the threshold, the transformation matrix is calculated.
Ⅵ. A geometric transformation is performed using the homogeneous transformation (expression 2).
(Return to Ⅲ)

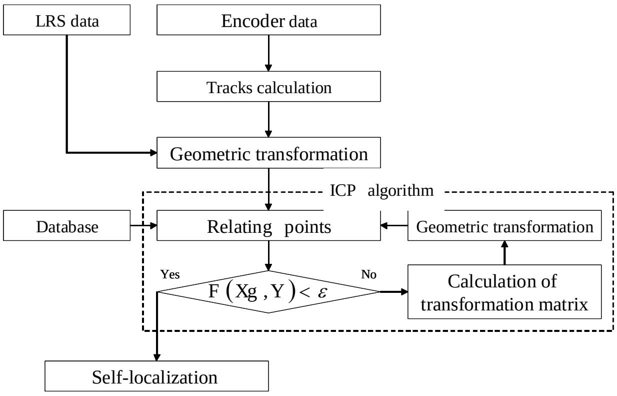


Fig. 2 Procedure for self-localization

3.3 Mapping method

The mapping procedure is shown below (See Figure 3).

Ⅰ.~ Ⅳ. See the corresponding steps in the procedure of self-localization.

Ⅴ. If the value of the evaluation function is less than the threshold, the transformation matrix at that time is the position of the robot. (Go to Ⅶ)
If the value of the evaluation function is greater than the threshold, the transformation matrix is calculated.

Ⅵ. A geometric transformation is performed using the homogeneous transformation (expression 2).
(Return to Ⅲ)

Ⅶ. If the value of the evaluation function is less than the threshold and converges, the map is constructed, and the database is updated based on this map.

Ⅷ. (Return to Ⅰ)

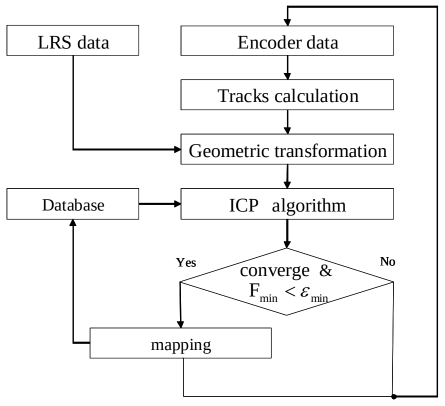


Fig. 3 Mapping procedure

4. Experiment

4.1 Experiment of self-localization

We performed experiments to verify the self-localization method proposed in this research. In experiment 1, the robot (Kitasap2) is arranged on ① in the environment of Figure 4, and robot presumes its self-position.

In experiment 2, to verify the robustness, the robot is lifted and is moved to position ② of Figure 4 compulsorily. Again, the robot presumes its self-position. The amount at this time of the movement is -1m to the direction of Y coordinates, and the robot orientation is rotated by 90 degrees.

We conducted each experiment 100 times. The error margins of self-localization are shown in Figures 5 and 6, respectively. The average error, the maximum error, and the standard deviations of the results are shown in Tables 1 and 2.

From Figure 5 and Table 1, it can be confirmed that the error of X coordinates and the error of Y coordinates are within ±3.0cm. Moreover, we confirmed that the orientation of the robot was able to be presumed within an error of ±0.01rad. Therefore it is proven that accuracy of this self-localization method is high.

From Figure 6 and Table 2, in the case where the robot is compulsorily moved, it can be confirmed that the estimated position converges in the correct vicinity of coordinates. And, it can be confirmed that the accuracy of self-localization is high. Therefore, it is proven that robustness improves with the accuracy maintained.

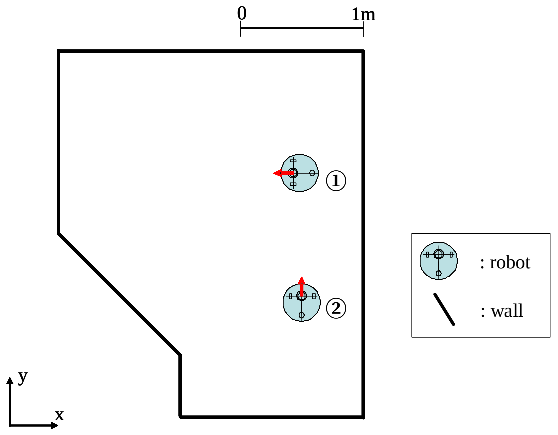


Fig. 4 Environment of the self-localization experiment

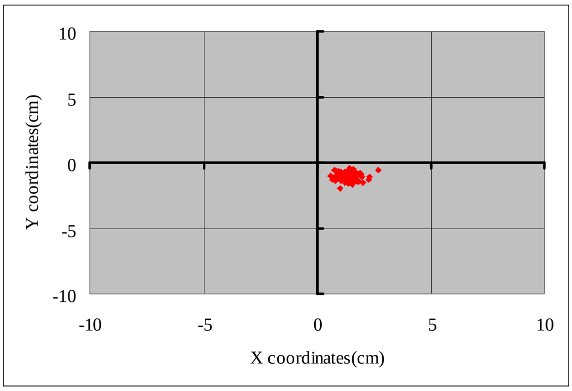


Fig. 5 Localization result of experiment 1

Table 1 Results of experiment 1

	X	Y
Average [cm]	1.4	-1.0
Maximum [cm]	2.7	-1.9
Standard deviation	0.4	0.3

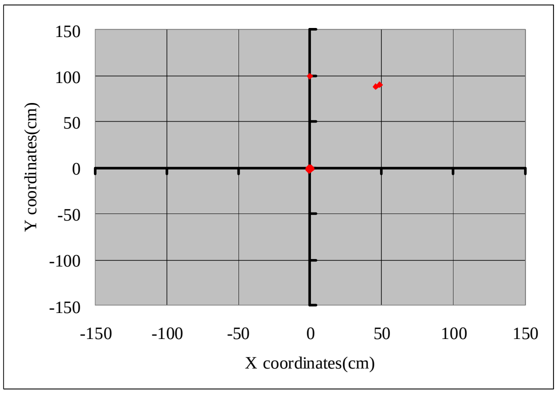


Fig. 5 Localization results of experiment 2

Table 2 Results of experiment 2

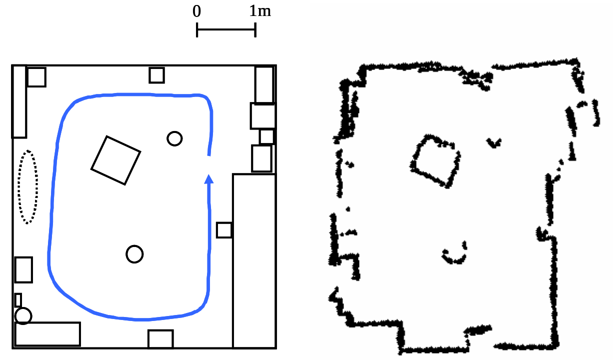
	X	Y
Average [cm]	0.1	-1.2
Maximum [cm]	0.7	-3.1
Standard deviation	0.3	0.4

4.2 Mapping experiment

We also performed an experiment to verify the mapping method proposed in this research. In this experiment, no map information is given to the robot beforehand, and the robot is arranged in an unknown environment (Figure 6). Figure 7 (a) is a map of the environment of Figure 6. The robot moves on the tracks shown by the arrow in Figure 7 (a), and constructs the map. The movement speed of the robot is about 20cm/sec. The map the robot generated is shown in Figure 7 (b).

From the experimental results, it can be confirmed that even if no map information is given to the robot beforehand, the robot is able to construct a map. However, the constructed map includes an error. And this experiment occasionally failed in mapping.

Fig. 6 Environment of the mapping experiment



(a) Map of experimental environment

(b) Results of the mapping experiment

Fig. 7 Map of the mapping experiment and experimental results

5. Conclusion

Our research has developed a self-localization method based on a fusion of Odometori and LRS (Laser Range Sensor) data. To solve the problems in our research up to last year, we used the ICP algorithm to match the LRS data with the database.

By using this method, the robot has improved robustness, and becomes able to construct a map without being supplied with a map beforehand.

The next problem is to improve the accuracy and the success probability of the mapping.

Thanks

I’d like to acknowledge the advice and assistance of the late Prof. Tadashi Kitamura of Kyushu Institute of Technology and pray for the repose of his soul.

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