A Robust Real-Time Mobile Robot Self-Localization with ICP Algorithm

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Abstract: Even if there are lots of researches on localization using 2D range finder in static environment, very few researches have been reported for robust real-time localization of mobile robot in uncertain and dynamic environment. In this paper, we present a new localization method based on ICP(Iterative Closest Point) algorithm for navigation of mobile robot under dynamic or uncertain environment. The ICP method is widely used for geometric alignment of three-dimensional models when an initial estimate of the relative pose is known. We use the method to align global map with 2D scanned data from range finder. The proposed algorithm accelerates the processing time by uniformly sampling the line fitted data from world map of mobile robot. A data filtering method is also used for threshold of occluded data from the range finder sensor. The effectiveness of the proposed method has been demonstrated through computer simulation and experiment in an office environment.

Keywords: Localization, ICP, Dynamic environment, Uncertain environment, Uniform sample, Filtering method.

1. INTRODUCTION

Mobile robot must recognize its location to move free in the room. Robot works to compare the previous information with the information from the sensor to recognize the real location, it calls 'self-localization'. For example, robot must know its present local information to move to the shortest cut from A to B. So, localization is calculated before starting movement. It is used for industry, robot, and traffic, etc., and mainly used in case of setting up the component to the desirable location or moving stuffs to any location with robot arm at factory.

Generally, the problem of self-localization can be solved by range sensor (sensor that is combined with ultra-sonic, laser or something). Localization is made using distance information from encoder and the information from the laser sensor in this article; the reason why laser sensor is used is that it can get more accurate result than ultra-sonic sensor or vision.

Another method of self-localization is to recognize the already known landmark or given grid type map. The approach based on landmark is the way to induce the conclusion by matching the location information that is already known to robot after selecting singular point from the sensor. Grid map based method is the way to assume the location of robot by matching all the information from the sensor with the given map. Two techniques are mainly used for grid basis method; one is based on the probability [4], the other is the approach by scan matching.

Probability based method is more effective than scan match method on localization as it seeks the possible location, however, more accurate result can be obtained by using scan matching method.

The representative methods among probability basis self-localization are Markov localization and Monte Carlo method. The key to Markov localization is to calculate all the number of cases that can be possible for localization to the peripheral environments.[6][7] more than 10 years, many a researcher has solved the localization using Markov method successfully. (Nourbakhsh, Powers, & Birchfield 1995; Simmon- s& Koenig 1995; Kaelbling, Cassandra, & Kurien 1996; Burgard et al. 1996). The key to localization of the other method of Monte Carlo is to express prior probability by weight to use random sample or particle, etc. This method was introduced by Handschin in 1970's, and it was also used for target tracing system by Gordon, Salmond, & Smith(1993). Also, Kitagawa(1996) applied it to statistics, and Isard & Blake(1998) used it widely in the field of Computer vision. The method that is commonly known as particle filter was ever used for dynamic probability communication by Kana-zawa, Koller, & Russell(1995).

Many a various ways have been studied for scan matching method that was based on sensor fusion. Cox established the way to match user's made map and sensor data to use CAD or the other tools for environment[2]. He transformed the read date to the straight line, and got rotation matrix and translation matrix matching the shortest line at perimeter.

Weiss made self-localization using histogram. He transformed the given map and the read data to angle histogram, and got rotation matrix and translation matrix using two similarities. Lu & Milios used the way to match point and point; [3] they used the way to get the shortest point to find the relationship between two points, and the way to search the near distance in the matching sphere. This way was known as IDC (iterative dual correspondence), which has the merits in characteristics to make robust localization even in the natural environment.

ICP algorithm basis localization that is suggested in this article has much difference compared to IDC in view of matching without getting the relationship between two points.

There are 2 merits using ICP algorithm for self-localization. First, real time process is available for reducing data volume by calculating the given map to be divided to the same interval. Process time of algorithm is proportional to input information from sensor and numbers of the given information.

In this article, 1000 or more points indicate $56.25\,m^2$. Average 350ms is used for localization algorithm that is processed on Pentium4 2.0Ghz computer to use Windows2000.

Second, smooth movement is available by eliminating the partial occlusion of map by material in dynamic environment on critical value basis. ICP algorithm matches distance based map and sensor information. Then, if bigger value is measured between map and sensor information than fixed value by the critical value, eliminating way is used on matching.

One of the problems to be solved on localization that is suggested in this article is that real time cannot be secured in case that the size of the given map is continuously growing. This problem can be solved with the method using information to be applied to matching only in consideration of Field of View in robot. Kid-napping, another problem, is main issue in the field of localization. It can be solved with the method calculating the available sphere on map through probability approach.

This article is composed as belows. The contents for explanation on localization, and introduction and merits on localization to use ICP algorithm is shown in Section2. Simulation from the suggested way and the contents, problems, and next developments in the result of experiment applying the way to robot practically is dealt in Section3.

2. Localization using ICP algorithm

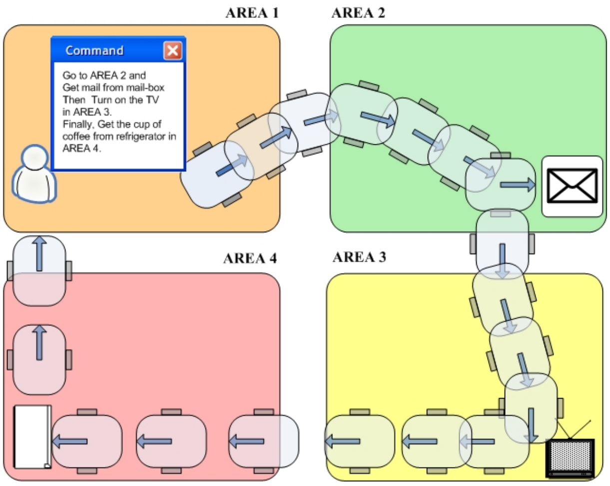

Fig. 1 Example of self Localization

One of the important job for self-motivated robot is to find out its accurate location in the peripheral environment. Robot measures the movement volume by using encoder information connected to the wheel when it moves. However, accumulated errors are occurred due to self-error of encoder, sliding, and friction. The way to find out location of robot uniting several sensors to solve the problem is commonly used. The mobile robots that were used in the previous industrial field has been controlled for its movements by inducing line or channel mark line such as magnetic tape typically. In this case, it is easy problem to trace self-location, but it has demerits impossible to make positive treatment. To solve this problem, vision process technique or research on assuming the location based on the distance sensor is executed. Experiment using PLS Laser Scanner of SICK and experiment loading to Power-Bot platform of Active media are described in this article. Localization by matching is based on the world map to know the peripheral environment in advance and information that is obtained from the present location of robot.

2.1 Localization using ICP algorithm [1]

ICP matching technique used in this article is used much to match point and point, line and line, and plane and plane in 3D field. Model Point Set and Data Point Set are necessary to match them. ICP method is the technique to match based on quaternion, and it can be described as

$$Q=[q_0\ q_1\ q_2\ q_3\ q_4\ q_5\ q_6] \tag{1}$$

Rotation matrix is

$$\vec{q}_R=[q_0\ q_1\ q_2\ q_3]^t \tag{2}$$

Then, it meets the condition of $q_0 \geq 0,\ q_0^{\,2}+q_1^{\,2}+q_2^{\,2}+q_3^{\,2}=1$. Translation matrix is defined as

$$\vec{q}_T=[q_4\ q_5\ q_6]^t \tag{3}$$

$P=\{\vec{P}_i\}$ is defined as measured Data Point Set to match Model Point set $X=\{\vec{x}_i\}$. N_x is numbers of Model Point Set, N_p is numbers of measured Point Set.

Then, mean square objective function is same as formula (4).

$$f(\vec{q})=\frac{1}{N_P}\sum_{i=1}^{N_P}\|\vec{x}_i-R(\vec{q}_R)\vec{p}_i-\vec{q}_T\|^2 \tag{4}$$

The center of mass of Measured Point Set P is indicated as $\vec{u}_P$, the center of Model Point Set X is indicated as $\vec{u}_X$.

$$\vec{u}_P=\frac{1}{N_P}\sum_{i=1}^{N_P}\vec{p}_i \ \ and\ \ \vec{u}_x=\frac{1}{N_x}\sum_{i=1}^{N_x}\vec{x}_i \tag{5}$$

And Cross-covariance matrix $\sum_{PX}$ of P and X is as below.

$$\sum\nolimits_{PX}=\frac{1}{N_P}\sum_{i=1}^{N_P}[(\vec{p}_i-\vec{u}_p)(\vec{x}_i-\vec{u}_x)^t]=\frac{1}{N_P}\sum_{i=1}^{N_P}[\vec{p}_i\vec{x}^t{}_i]-\vec{u}_p\vec{u}_x^{\,t} \tag{6}$$

Quaternion Matrix is as below.

$$Q(\sum\nolimits_{PX})=\begin{bmatrix} tr(\sum_{PX}) & \Delta^T \\ \Delta & \sum_{PX}+\sum_{PX}^{\ T}-tr(\sum_{PX})\mathrm{I}_3 \end{bmatrix} \tag{7}$$

Then, I_3 is 3 x 3 unit matrix, $\Delta=[A_{23}\ A_{31}\ A_{12}]^T$, $A_{ij}=(\sum_{px}-\sum_{px}^{\ T})_{ij}$

Getting max. eigen value of matrix $\sum_{PX}$, rotation matrix $\vec{q}_R=[q_0\ q_1\ q_2\ q_3]^t$ is obtained..

$\vec{q}_T=[q_4\ q_5\ q_6]^t$ is given by the formula stated below.

$$\vec{q}_T=\vec{u}_x-R(\vec{q}_R)\vec{u}_p \tag{8}$$

Then,

$$R = \begin{bmatrix} q_0^2 + q_0^2 - q_0^2 - q_0^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2) \\ 2(q_1q_2 + q_0q_3) & q_0^2 + q_2^2 - q_1^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 + q_3^2 - q_1^2 - q_2^2 \end{bmatrix} \quad (9)$$

In conclusion, least squares quaternion operation is $O(N_P)$, and it is shown again as

$$(\vec{q}, d_{ms}) = O(P, X) \quad (10)$$

Here, d_{ms} is mean square point matching error.

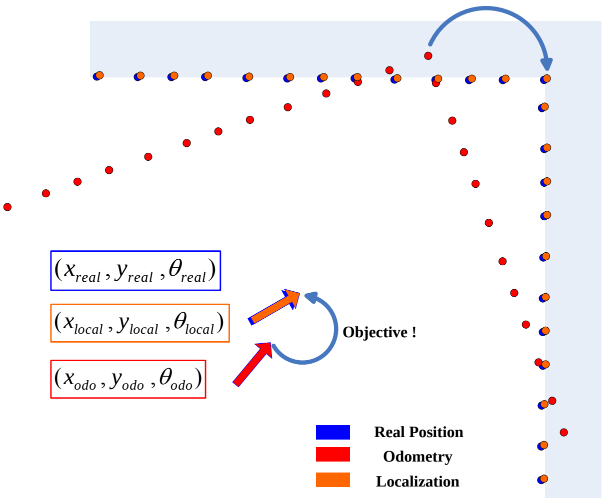

Fig2. Explaining of self localization process

ICP algorithm is made by 4 procedures. First, point set P of N_P and point set X of N_x are given. Initial condition is $P_0 = P, \vec{q}_0 = [1,0,0,0,0,0,0]^t$, k=0 , and iteration is terminated if error is less than τ.

ⓐ Get the shortest distance.. $Y_K = C(P_K, X)$

ⓑ Get quaternion matrix for matching.

$$(\vec{q}, d_k) = O(P_0, Y_k)$$

ⓒ Apply quaternion matrix in ⓑ to set P.

$$P_{k+1} = \vec{q}_k(P_0)$$

ⓓ If mean square error isles than τ, terminate iteration. If not, execute ⓐ. The above process can be described in Fig2.

2.2 Uniform sample method

Uniform Sample World-Map method was used in this article to reduce numbers of World-map for making operation speed rapid and eliminating noise. Made World-Map is used for marching robot- measured information at present.

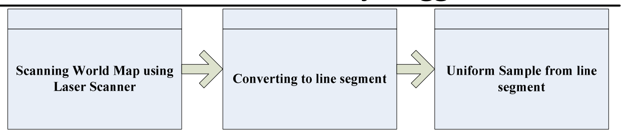

Fig. 2 Uniform sample world map procedure

2.3 Localization Procedure

Procedure of Localization using ICP is made such as in Fig3.

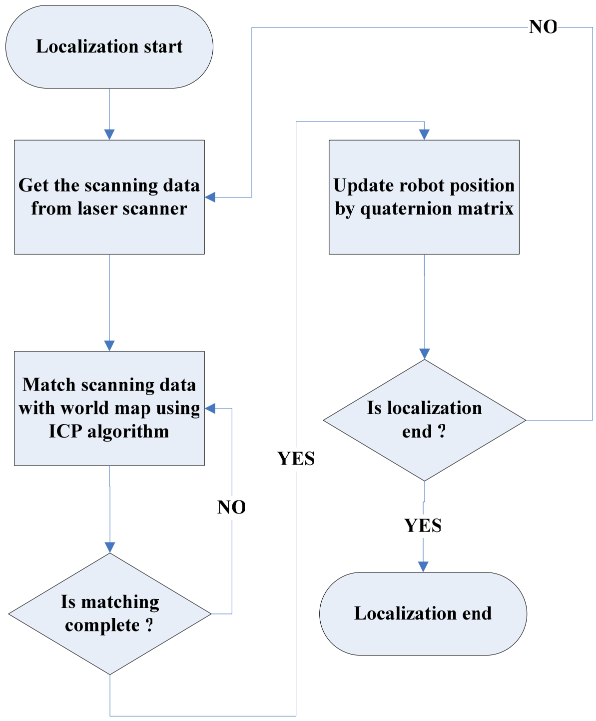

Fig3. Localization with ICP procedure

The Localization is composed of 2 loops in large; they are total localization loop and the loop to get quarternion matrix in which ICP algorithm was executed.
Total loop meets the condition if action of robot is terminated. ICP algorithm loop is terminated if mean square error is less than Threshold.

2.4 Robustness of self-localization using ICP algorithm

ICP algorithm executes matching based on distance. Using this characteristics make robust treatment for occlusion or obstacle. In case the distance between robot-scanned data and world map is bigger than the fixed level, the above method is described in Fig4.

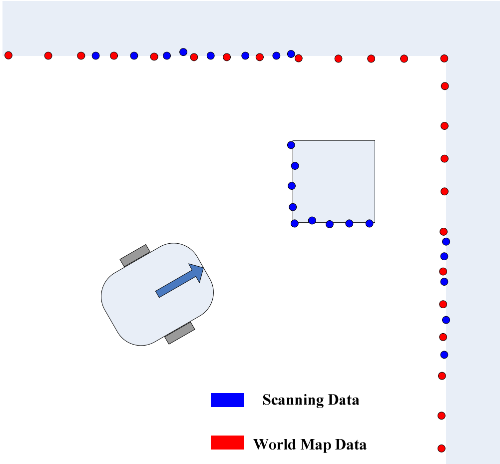

Fig4. Filtering method using ICP algorithm

The case that has obstacle in the course of matching red data Set and blue data Set is described in Fig4. If obstacle is existed, it effects on getting accurate result as ICP algorithm is operated to noise in the course of making quarternion matrix. To solve this problem, distance-based Threshold technique was used. In the circumstance that data value of measured sensor is far from the fixed distance on world map, it is considered to obstacle and excluded when matching. Thus, numbers of using information are reduced and operation speed is increased. Also, it has the merit to be realized.

2.5 Software architecture of ICP algorithm

Software architecture must be considered for the efficient resources management and real time. I adopted Object Oriented Programming method, and designed to enhance the recycling and transplanting of the program in this article. The program for experiment was made on Microsoft Visual studio 6.0, and Power bot and Active Media Robotics Interface Application (ARIA) of Active Media was used. The role of ARIA was applied to the part for driving of robot platform such as connecting to robot, getting sensor value, and getting encoder data. ICP algorithm that executes matching is made by modularization to meet Object Oriented Paradigm (OOP), and it has the merit to be easily available anywhere to use. Also, communication between Modules and data process were made by the structure that can process efficiently. Software architecture that compose ICP is described in Fig5., and it is real module to execute ICP algorithm suggested in this article. Connection relationship of the program per OOP is indicated in Fig6.

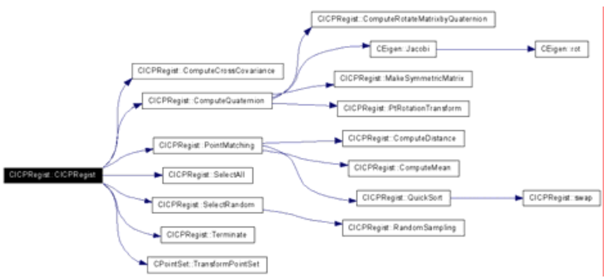

Fig5. Class diagram of ICP algorithm

Fig6. Structure of self-localization program with Object Oriented Program method.

3. Conclusion and Experiment Contents

I selected the development method of verifying algorithm on simulator and applying to real robot for the efficiency of work. For simulator, tool in ARIA was used, as it has modeling for laser sensor and encoder in reflecting on accumulated error when robot is moved. To get the result near to reality, I experimented by adding noise at random to world map in addition. In conclusion, I consider what is the problem to be improved, comparing the result of simulation to real result.

3.1 Simulation environment and experiment results

Simulation was made on notebook of Pentium3 800Mhz, RAM 256MB, Windows2000 professional specification, and real experiment was executed on Pentium4 2.1Ghz, RAM512MB, Windows2000 professional.

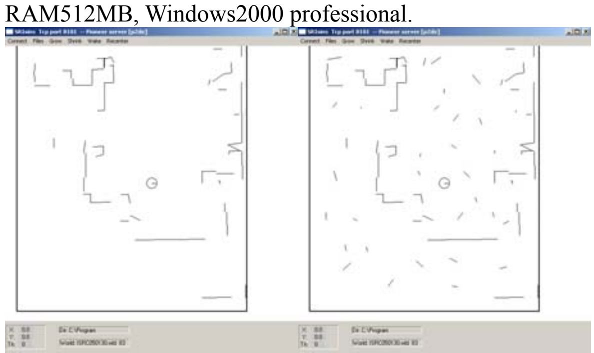

Fig7. Screen shot of simulator (left) and artificial noisy environment (right).

3.2 Experiment environment and Method Explanation

Experiment environment can effect strongly to the result. Robot system responds very sensitively according to complex environment or the environment with lots of movable materials or intensity of illumination. Experiment was executed in the environment that is similar to office, and the floor was not much slippery. Ground with glass and mirror that cannot be measured in characteristics of Laser scanner is included by 5m x 10cm. Such a environment resulted increasing errors when robot was approached to glass wall.

Fig8. Experiment environment (left) and initial position of power bot in the Lab. (right).

To verify localization, the method to set up for the initial location by marking on the floor was used. After marking the initial location, I had moved robot freely and moved to the initial location. It can be verified comparing trace by encoder and that of localization. The specification used in the experiment is as Table 1. PLS Laser Scanner of SICK for sensor was used and the specification is as Table2.

Table 1 Specifications of robot platform (Power bot).

Length	85cm	Battery	24V sealed, lead-acid
Width	63cm	Wheel radius	13.5cm
Height	47cm	Wheel width	9cm
Weight	120kg	Steering	Differential
Translate speed max	2.1m/s	Run time, base platform	2.5hr
Gear ratio	22.3:1	Wheel encoder resolution	1024 tick

Table 2 Specifications of laser scanner (PLS).

Scanning angle(°)	180
Scanning distance(m)	4
Response time(ms)	80
Resolution(mm)	70

3.3 Experiment results

Encoder error to the robot-moved distance and localized results are shown in Table3. The result of measuring in rotating robot is shown in Table4.

Table 3 Result of localization using ICP.

	Odometry			Localization		
Start point	x(mm)	y(mm)	θ(°)	x(mm)	y(mm)	θ(°)
	0	0	0	0	0	0
End point	-128.5	120.9	-16.1	-63.3	24.0	-3.0

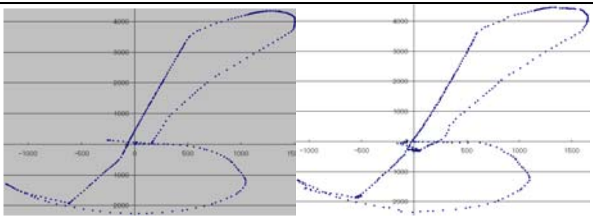

Fig9. Random motion trajectory by encoder. (left) and localization trajectory (right).

Table 4 Result of localization using ICP.

	Odometry			Localization		
Start point	x(mm)	y(mm)	θ(°)	x(mm)	y(mm)	θ(°)
	0	0	0	0	0	0
End point	169.2	34.3	-12.9	56.0	49.6	-9.7

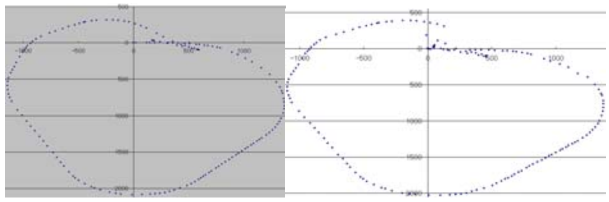

Fig10. Circle motion trajectory by encoder. (left) and localization trajectory (right).

Table 5 Result of localization using ICP.

	Odometry			Localization		
Start point	x(mm)	y(mm)	θ(°)	x(mm)	y(mm)	θ(°)
	0	0	0	0	0	0
End point	-866.1	-41.3	-4.8	-398.9	2227.3	2.1

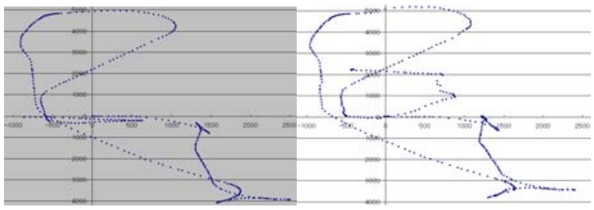

Fig11. Random motion trajectory by encoder. (left) and localization trajectory in glass environment(right).

3.4 Interpretation of Experiment and Review

The result on the experiment of random movement of robot was described in Table3 and Fig9. The result of experiment on circular movement was shown in Table4 and Fig10. The result of experiment in glass wall environment was described in Table5 and Fig11. As shown in Table3, error of encoder, which was occurred to x axis by -128.5mm, was corrected to 65.2mm, and y axis was corrected to 96.9mm, θ was corrected to 13.1°. Then, robot movement distance is more than about 20m. Considering these items, I think that it is very exact result.

3.5 Improvements and next developments

Self-localization method using ICP algorithm showed real time and robustness in this article, but a case to fall into the local minima was happened. As ICP is the way to match from the present area to the nearest place, the case that has no right solution was even occurred. To solve such problems, there is a way to exclude the case that variant is very big or coordinates of robot are existed to the improper location, referring to the past value. Another problem is the case that robot is laid to the unrecognizable area by Kid-napping or electricity power is suddenly off. To solve this problem, there is a way to select the most available place on world map, using probability method. Besides, it can be solved with Global positioning system using indoor GPS or Global land mark, and beacon, however, these ways have problems that can not be applied practically, as they can not secure the accuracy to be used in robot and economical burden is big for setting up for the facilities.

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