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Development of Fast Map Building Algorithm for Merchandise Location Guiding Mobile Robot

Jin-Pyo Hong[1],You-Jun Choi[2] and Kyi-Hwan Park[3]

[1,2,3]Department of Mechatronics, Gwangju Institute of Science and Technology, Gwangju, Korea
(Tel : +82-62-970-2408; E-mail: {jphong,ychoi,khpark}@gist.ac.kr)

Abstract: In the public space, we need first of all the map building to guide the person into the desired position. For realizing this functionality, we propose the fast map building method combining the wall following algorithm and the segment estimation algorithm. First, the process of fast map building algorithm is introduced and secondly, the navigation algorithm for following the surface of a wall by IR sensors is proposed and local map building method by estimation of line segment is shown. We derive the correlation between the orthogonal wall distance and IR sensor data using trigonometric functions and the similarity ratio of a triangle. Finally, we verify that our proposed method is sufficiently valid as describing the experimental results using our developed mobile robot platform, GIMOR(GIST Mobile Robot)-I.

Keywords: Fast map building, IR sensor, Laser Range Finder, Navigation Algorithm, Local map building

1. INTRODUCTION

Recently, mobile robots are more and more used for guiding task in the public area like as market, post office and exhibition hall etc. To do guiding task or other, it is necessary to make a map about a wall and obstacles. Moreover, map building is indispensable because a location of obstacles, i.e. market shelves, is changed by needs frequently. Therefore, a robot have to make a decision to move to empty space from the obstacle and also need to know map information.

The general method to obtain rapidly the map is to use Laser Range Finder[LRF][1][2][3]. It has an ability to scan the environment in the range of from 0 degree to 180 degree and the mobile robot can be navigated by using LRF measured data. Even though these methods have advantage of long range data acquisition, the mobile robot should move slowly because of bandwidth of the long range sensor is lower than short range sensors.

Another method to build a map is to utilize the Sparse Sonar Data[4][5]. This method is much time-consuming method because the range of the sonar sensor is limited to 3 - 6 meters at most and the measured data is not exact point data but broadly detected data because the ultrasonic wave is spread

Therefore, several kinds of sensors are needed for fast map building. Odometers ,a goniometer and LRF were used for a local map building [7]. In the paper [7], robot posture and position were obtained by the information from odometers and the goniometer and then the obstacle data in local map was generated from LRF scan data.

In contrast with previous work [7], IR sensors and LRF have been adopted in our paper work for navigation following the surface of a wall which are comparatively precise since they are point detection sensors. Our proposed method is that we perform the fast map building process combining the wall following algorithm and the segmentation estimation algorithm.

In this paper, firstly, we introduce the navigation algorithm for following the surface of a wall in section 2. From the correlation of the sensor data, we can make the mobile robot controlled following the wall contour. Secondly, the local map building algorithm is described in section 3. Finally, as we show you the experimental results about the mobile robot wall following control data and map building data, we verify that our proposed method is sufficient to have good performance in the map building method.

2. NAVIGATION ALGORITHM FOR FOLLOWING THE SURFACE OF A WALL

2.1 Wall Following Process

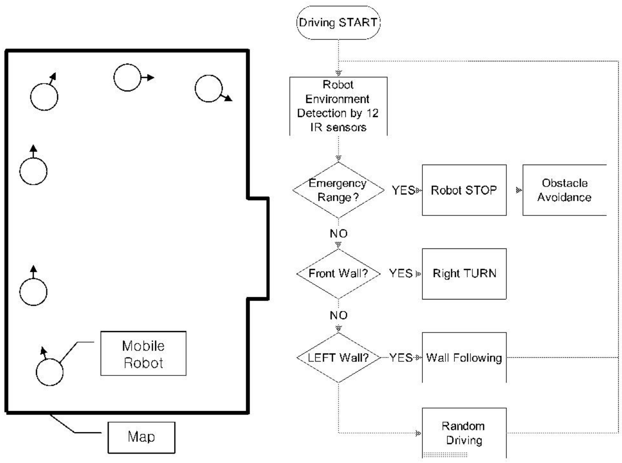

Fig. 1 Wall Following Process

This algorithm has been developed for obtaining the wall information and the obstacle data in closed area at the same time. Before describing the wall following algorithm,I will show you the control process in figure 1.

The mobile robot start going anywhere if there is not any wall detection. After the mobile robot detects the environment by twelves IR sensors in figure 2, it determine the behavior of itself according to the emergency status, right turn status, wall following status and random driv-

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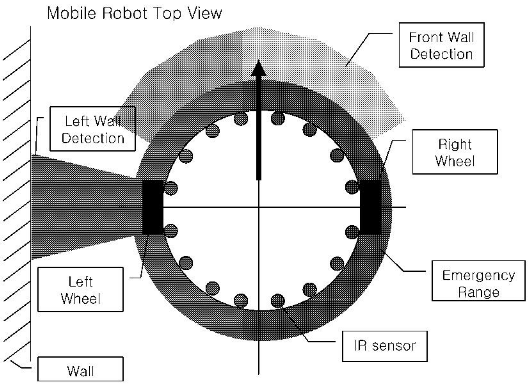

Fig. 2 IR sensor distribution

ing. When the mobile robot have an right turn, we utilized the forward four IR sensors arrayed at regular intervals. If the detection range is smaller than threshold value for front wall detection, the mobile robot can determine that the front wall exists and it starts right turn.

2.2 IR Sensor Modeling for the wall following

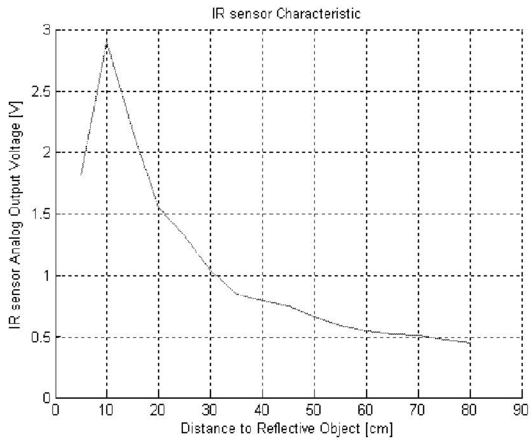

Fig. 3 IR sensor nonlinear characteristic

There are many kinds of sensors for the detection of the obstacle and the control of the mobile robot. Since a IR sensor is a point-detection sensor, it is very good to use as a feedback sensor for controlling the wall-following in spite of the nonlinearity in figure 3.

GIMOR-I has several IR sensors which have capability to detect an object far from 10∼80 cm. They are distributed in the radial direction and located with constant degrees as shown in figure 2 because the mobile robot have ability to get the more previous wall information before it does not pass through. Among these sensors, we use two IR sensors for GIMOR-I to navigate in a parallel direction with the wall without a sensor for getting robot orientation. Two IR sensors are located near to the left wheel in figure 4.

Since IR sensor used for measuring the distance between the center of robot and the wall has nonlinearlity, we interpolate the sensor data by curve fitting with the polynomial functions with experimental data [9]. So we should make a model for IR sensors by using the following fifth order equation in the range of 10∼80 cm.

$$y = A_0 + A_1x + A_2x^2 + A_3x^3 + A_4x^4 + A_5x^5. \quad (1)$$

where x is the output of IR sensor and y is the estimated distance.

2.3 The Correlation between the IR sensors data and the orthogonal wall distance

As shown in figure 4, we can derive the geometric correlation equations from the law of cosines, the ratio of the triangle, and the area equality as follows. If d_1 and d_2 are obtained from the IR sensors, we can know the d_w from the the second law of cosines and then we can estimate the d_3 according to the similarity ratio of the triangle. Since we know the sensor angle, we can derive the d_5 from the area equality in the triangle composed of the d_1, d_3 and d_5. Also, We can estimate the orientation of the mobile robot from the correlation between the wall angle and the sensor angle.

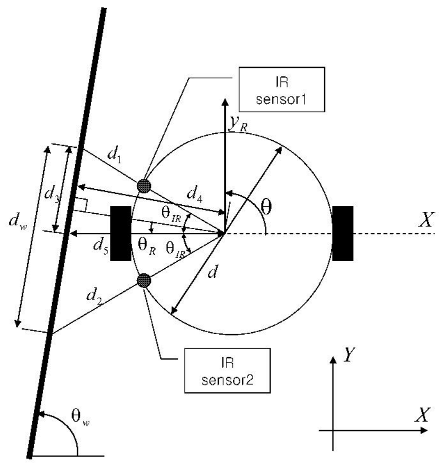

Fig. 4 Localization

$$d_w = \sqrt{{d_1}^2 + {d_2}^2 - 2d_1d_2\cos 2\theta_{IR}}, \quad (2)$$

$$d_3 = \frac{d_1 d_w}{d_2}, \quad (3)$$

$$d_4 = \frac{d_1 d_2 \sin 2\theta_{IR}}{d_w}, \quad (4)$$

$$d_5 = \frac{d_3 d_4}{d_1 \sin 2\theta_{IR}}, \quad (5)$$

$$\theta_R = \pm\arccos(\frac{d_4}{d_5}) \text{ for } d_3 < \frac{d_w}{2} \text{ and } d_3 > \frac{d_w}{2}, \quad (6)$$

$$\theta = \theta_w + \theta_{IR}. \quad (7)$$

(8)

where,
d_1, d_2: Measured distance from IR sensor1,2,
d_w: Measured wall distance,
d_3: Distance between a point detected by IR sensor1 and a cross point of wall and mobile robot x axis,
d_4: Orthogonal distance of the surface of a wall and mobile robot center point,
d_5: Distance of the surface of a wall and mobile robot center point in the direction of mobile robot x axis,

θ_R, θ_w: Pose of Robot, Pose of the wall.

2.4 Mobile Robot Control for the wall following

In figure 5, our objective is to control that the center of the mobile robot follow the desired offset path equal to the wall path. The control input is the error between the desired distance and the measured orthogonal wall distance.

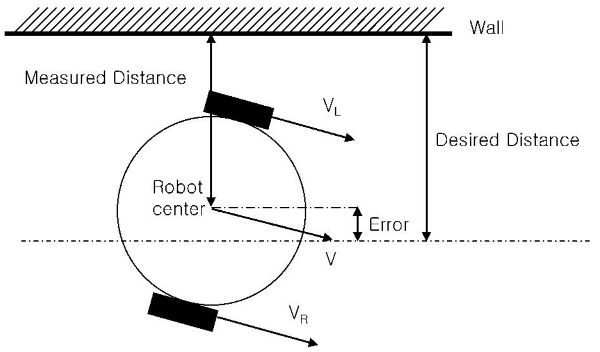

Fig. 5 Mobile robot control for the wall following

$$d_e = d_d - d_4, \tag{9}$$

$$V_L = V_C + (K_p d_e + K_d \dot{d_e} + K_I \int d_e), \tag{10}$$

$$V_R = V_C - (K_p d_e + K_d \dot{d_e} + K_I \int d_e). \tag{11}$$

where,
d_e: Distance error,
V_L, V_R, V_C: Left wheel velocity, Right wheel velocity, Nominal Speed
K_p, K_I, K_d: PD controller gain.

since our mobile platform, GIMOR-I, has two-wheel differential drive with 2 additional points of contact, we can make the controller eq.10 and eq. 11 using the PID controller with anti windup algorithm.

3. LOCAL MAP BUILDING

It is necessary to build a map for the navigation at the market since the location of market shelves are changed by need frequently. Therefore, in this paper, we suggest a local map building algorithm using Laser Measurement System (LMS).

3.1 Data Acquisition by Laser Measurement System

The Laser Measurement System(LMS) that we have used in this paper has a maximum scanning distance of 30 meters approximately. It has 1 degree resolution 0 degree to 180 degree, the interval is 1 degree. Therefore the ith element of the array is the distance of ith degree from origin of LMS as shown in table 1.

The primary raw data is transferred to a SBC(Single Board Computer) on the mobile robot as an array of MeasuredData[i] in polar coordinate, which stands for the obstacle distance in the ith scanning angle of the LMS. A plotted map with raw data from LMS is shown as figure 6.

Table 1 Scanning Data array from 0 to 180 degree.

Angle[i]	**0**	**...**	**90**	**...**	**180**
MeasuredData[i]	37	...	284	...	148

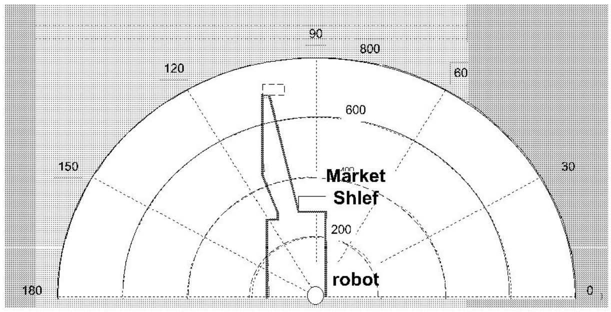

Fig. 6 the Scanning Map of LMS

3.2 The Segments Estimation Algorithm

The first process of the map building algorithm concerns the laser scan data acquisition we have mentioned before. However, we just have a laser scanning data from LMS. Therefore it is necessary to recover the segments estimation that forms the actual visibility region from the point data that LMS gives. We get poly-lines with the laser scanning data obtained as an ordered list of polar coordinates (r, θ) where market shelves may be found. Thus to execute the segments estimation, we have to convert from polar coordinate to rectangular coordinate by using following eq.12.

$$\begin{pmatrix} MD[i]_x \\ MD[i]_y \end{pmatrix} = MD[i] \begin{pmatrix} cos\theta \\ sin\theta \end{pmatrix} + \begin{pmatrix} R_x \\ R_y \end{pmatrix} \tag{12}$$

where, MD is MeasuredData, R_x and R_y are current x and y coordinate of robot, respectively.

To detect edges of market shelves, at least two segments which belongs to the same straight line will be needed as shown in figure 7. The distance between two

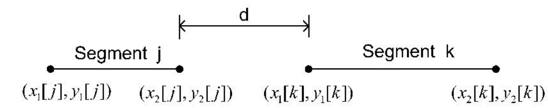

Fig. 7 Market shelf representation by segments

segments which is going to be movable passage is calculated by following eq.13:

$$d = \sqrt{(x_2[j] - x_1[k])^2 + (y_2[j] - y_1[k])^2} \tag{13}$$

where d is a distance between two segments.

If an angle of robot is moved by θ from the origin, the scanning map by measured data from LMS is also rotated by θ. To find out market shelf, we need to check whether measured elements are on the same object or not by comparing slope of continuous elements. However a cost of this method is too high because of a division operation of calculating slope of continuous elements. Therefore, we check the moving angle θ in order to reduce the cost first. Then, we equate a rotation transformation operation by multiplying 2×2 transformation matrix which produces rotation about the origin to make zero-degree-scanned data from the origin using eq.14.

$$\begin{pmatrix} x_2 \\ y_2 \end{pmatrix} = \begin{pmatrix} cos(\theta) & -sin(\theta) \\ sin(\theta) & cos(\theta) \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \end{pmatrix} \tag{14}$$

To estimate a length of each segment, we have used geometrical criterion. Among measured elements if a distance between y coordinate of two continuous elements p_i, p_{i-1} is less than defined threshold value ζ_1, we assume that these elements belong to the same object in the figure 8. Similarly, if distance between x coordinate of two continuous elements p_i, p_{i+1} is less than ζ_2, we assume that these elements belong to the same object. The selection of all line segments x_j that contribute to

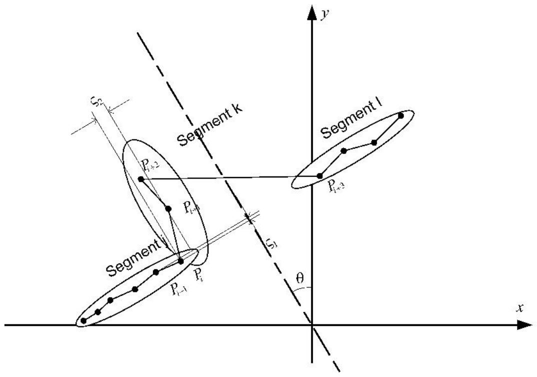

Fig. 8 Estimation of segements

the same line can be done in a threshold-based manner according to following eq.15.

$$(p_{i+1} - \overline{p_i})^T (p_{i+1} - p_i) \le \zeta_i \tag{15}$$

where ζ_i is a threshold value and $\overline{p_i}$ is the representation of the reference line, respectively.

However, the approach of eq.15 does not consider of error measurements for each measured scan data and therefore we have an uncertainty for each line segment. To reduce these uncertainty, we check the length of line segment according to following eq.16

$$(sx_2 - sy_2)^T (sx_1 - sy_1) > \xi \tag{16}$$

where ξ is a threshold value for reducing uncertainty and sx_i and sy_i are x and y coordinates of each line segments, respectively.

3.3 Fast Map Building Algorithm

The general map building algorithm is shown in fig.9 This algorithm has advantage which can obtain accurate map information, but long execution time is needed until completing map building if we use just same kind of sensor. Therefore, we suggest fast map building algorithm by LRF and IR sensor fusion method. In this algorithm, in order to increase speed of map building and stable movement of mobile robot, we measure local map data just one time at each corner of map and find out maximum movable position at the same time using LMS. We

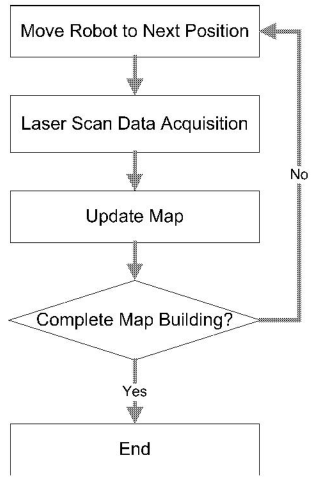

Fig. 9 General Map Building Algorithm

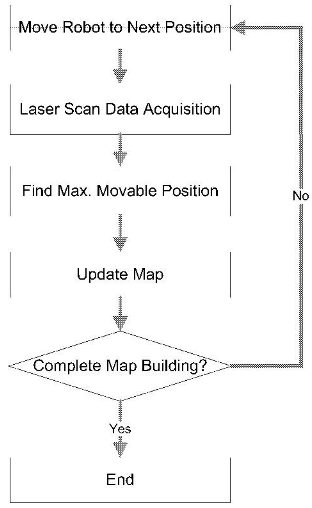

Fig. 10 Fast Map Building Algorithm

first find out the longest distance from the robot among measured laser data to find out a movable position. Then, the segment estimation algorithms are performed with the longest distance value from robot. After then, the maximum movable position is calculated between two close segments. Finally, local map is updated with respect to each heading direction of robot, i.e. east, west, south, north, and total map is updated by fusion all of the maps. If total map is not complete then we move robot to next maximum movable position without measuring laser scan data using wall following algorithm by IR sensor data, and do same process until total map is built completely. The fast map building algorithm is shown in fig. 10.

4. EXPERIMENTAL RESULTS

We are using a mobile robot GIMOR-I (See fig.11) with a Single Board Computer(SBC), Pentium-IV 4GHz Processor,two digital signal processors with 150MIPS and differential drive. It is equipped with 16 IR sensors for the wall-following navigation. It is also equipped with a Sick laser ranger finder for a long distance measurement.

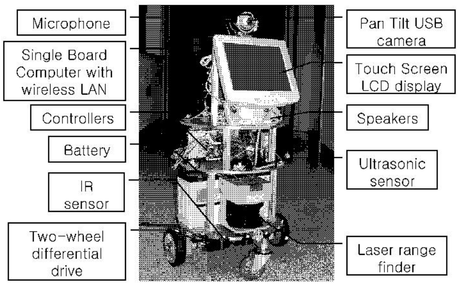

Fig. 11 Service Robot GIMOR-I

Firstly, we accomplished the experiment about the control performance of the mobile robot when it is driven to a straight wall according to the initial condition of the mobile robot. Figure 12 shows the control performances according to the robot initial condition. Figure 12 (a),(b),(c) represent the results of orientation 0 degree and 45 cm offset, the orientation 30 degrees and 45 cm offset and the orientation -30 degrees and 45 cm offset respectively. We can see that maximum offset error is about 4cm and the mobile robot is stabilized in the range of 10cm. In this experiment, we utilized the PID controller with anti windup algorithm for prohibiting the unstability due to the integral error.

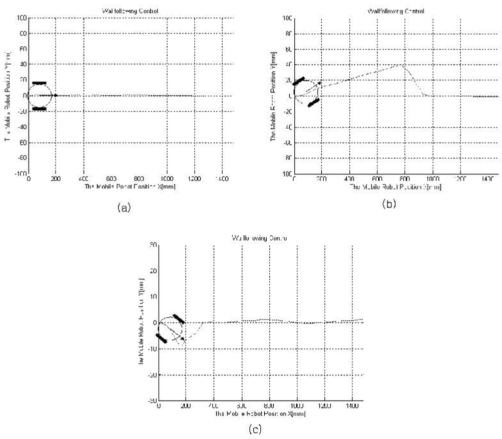

Fig. 12 Straight Wall Test

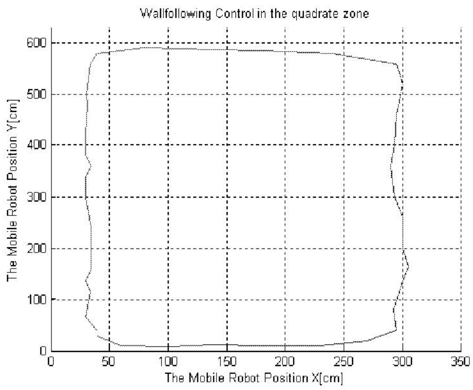

Fig. 13 Wall Following Control Test

Since we have suggested map building algorithm for the purpose of using at the market, a shelf-like object is set in the one section of market like-large area for a test environment as shown in fig. The size of the test environment is 3.2 meters by 6.5 meters. We assume that there are no people in the test environment and every market shelf have rectangular shape.

We executed the wall following test in the test environment. By the our method proposed in section 2, the mobile robot has been tested. Figure 13 shows the contour test result. As we wish, the contour data is nearly similar to an original map and the maximum error is less than 15cm. Why the map error is generated is that the error is sensitive to the reflexibility of the wall.

A local map of the test environment is generated by LMS. Fig.14 is a result of finding the movable longest distance. It shows that how the GIMOR-I estimates the movable longest distance. First, GIMOR-I finds the

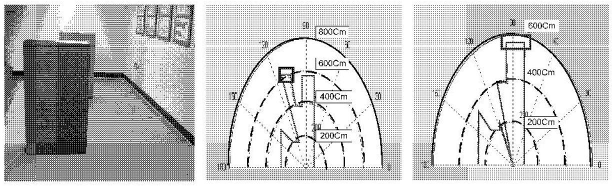

Fig. 14 The Longest Distance Estimation

longest distance coordinate from robot and calculates a length of empty passage around the found the longest distance coordinate. Second, GIMOR-I checks whether robot can go through or not. If calculated empty passage is not movable (less than 2 times of robot's width), after that GIMOR-I begins to find out next maximum distance and do same process until robot finds out movable empty passage.

Fig.15 shows how fast map building algorithm is working. As we can see in fig.15, GIMOR-I measures

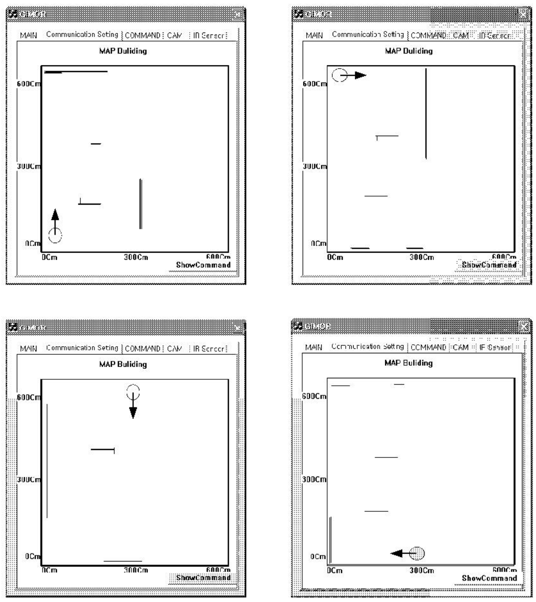

Fig. 15 Fast Map Building Algorithm

laser scan data and calculates maximum movable position. Then, the segments estimation algorithm is executed to make a local map with respect to robot's heading direction. After that, it moves to next calculated movable position using wall following navigation with IR sensors, and do same process until it builds a map completely.

Final map result of fast map building is shown fig. 16. Left side of fig.16 shows a builded map by fast map building algorithm and right side of fig.16 shows a real experimental environments.

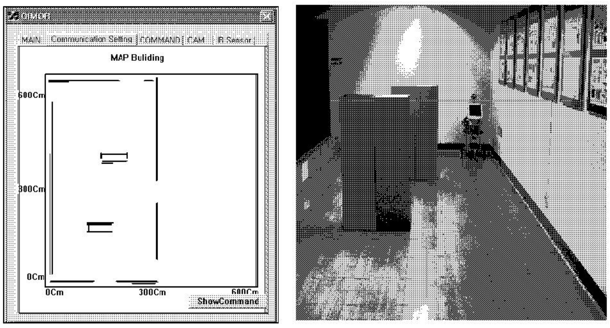

Fig. 16 Final result

5. CONCLUSION

Navigation algorithm for following the surface of a wall and local map building method has been developed for the fast map building in changeable public space.

The distance measurement method proposed from IR sensors data was first presented with the advantage capable of prediction about the wall information. We can know that the error is generated on the kinematic error ,the sensor noise and the wheel slip. So, we should make an error model and develop another advanced wall following method with four IR sensors.

The maximum movable position is estimated by the long distance estimation algorithm. Local map is built by the segments estimation algorithm at each estimated location which obtained by the long distance estimation algorithm. Final map is built by fusion of each local map.

Our approach is better than previous map building methods because the robot can move to desired position as fast as it can safely by proposed wall following algorithm. At the same time,the mobile robot can build a large scaled map by proposed segments estimation and map building algorithm. Therefore, our proposed map building algorithm increases map building speed.

As the future work, we should develop the larger map building method not detected at once by LRF. Since our mobile robot is used in the public space, the navigation algorithm and the fast map update algorithm also should be developed.

REFERENCES

[1] A. Lallement, A. Siadat, M. Dufaut and R. Husson,"Laser-Vision Cooperation for Map Building and Landmarks Recognition", *ISIC/CIRA/ISAS Joint Conference*, pp. 387-392, 1998.

[2] Benjamn Tovar, Rafael Murrieta-Cid and Claudia Esteves,"Robot Motion Planning for Map Building", *Proceeding of the 2002 IEEE/RSJ Intl. Conference on Robots and Systems EPFL, Lausanne, Switzerland. October 2002*

[3] R. Barber, M. Mata, M.J.L. Boada, J.M. Armingol, M.A. Salichs,"A Perception System based on Laser Information for Mobile Robot Topologic Navigation", *The 28th Annual Conference of the IEEE Industrial Electronics Society (IECON'2002), Sevilla, Spain, November 5-8, (2002)*

[4] Se Jin Lee, Dong Woo Cho, Wan Kyun Chung, Jong Hwan Lim and Chul Ung Kang,"Feature Based Map Building Using Sparse Sonar Data", *International Conference on Intelligent Robots and Systems*, pp. 1648-1652, 2005.

[5] F.J. Toledo ,J.D. Luis, L.M. Tomfis, M.A. Zamora, H. Martnez"Map Building with Ultrasonic Sensors of Indoor Environments Using Neural Networks", *Systems, Man, and Cybernetics, 2000 IEEE International Conference on Volume 2, 8-11 Oct. 2000 Page(s):920 - 925 vol.2*

[6] Joseph Canou, Gilles Mourioux, Cyril Novales, Gerard Poisson,"A local map building process for a reactive navigation of a mobile robot", *Proceeding of the 2004 International Conference on Robotics and Automation. New Orleans, LA. April 2004*

[7] Joseph Canou, Gilles Mourioux, Cyril Novales, Gerard Poisson, "A local map building process for a reactie navigation of a mobile robot", *International Conference on Robotics and Automation*, pp. 4839-4844, 2004.

[8] Siegwart, Nourbakhsh,"Introduction to Autonomous Mobile Robots",*The MIT Press, p159 - p163*

[9] Steven C. Chapra, Raymond P. Canale, ,"Numerical Methods for Engineers ",*Mc Graw Hill, p533 - p539*