Intelligent Fuzzy Motion Control of Mobile Robot for Service Use

S. V. Ulyanov *, K. Yamafuji *,
K. Miyagawa *, T. Tanaka * and T. Fukuda **

* University of Electro-Communications, 1-5-1 Chofu, Tokyo 182, Japan
** Nagoya University, 1 Furo-cho, Chikusa, Nagoya 464-01, Japan

Abstract. The intelligent mobile robot for service use with manipulators are moved in unstructured environments. Strategy for planning, environment recognition using two kinds of sensors and locomotion control to realize autonomous locomotion of the mobile robot are described. Fuzzy qualitative simulation, GA and hierarchical node map have revealed their effectiveness for path planning of the mobile robots.The results of fuzzy robot control simulation, monitoring and experimental investigations are presented.

Keywords: Mobile Robot for Service Use, Path Planning, Human-Robot Interaction, Genetic Algorithms, Hierarchical Node Map, Fuzzy Control

1 Introduction

The intelligent robots for service use in buildings, especially in office buildings are proposed. The concept and required specifications of the robots have been discussed in [1,2]. In this paper, strategy for planning, environment recognition using two kinds of sensor and locomotion control which are important to realize autonomous locomotion of the robot are described. Genetic algorithm (GA) and hierarchical node map (HNM) have revealed their effectiveness for path planning. Position and attitude of the robot can be recognized by the wheel motor encoder's signals. Environment including obstacles is detected by five ultrasonic sensors installed on the robot. Experiments of locomotion control on the manufactured robot based on fuzzy control method show that the proposed methods are useful for autonomous locomotion of the robot.

The main idea of human interaction with mobile robot of service use and main technological operation are in Fig.1a and 1b illustrated.

We developed (Fig. 1) the robot for four kinds of service (transport, guidance, cleanning floor and security guard). For working in building, robot must be able to open door and operate elevator. In this cooperation research paper, a new locomotive robot has been developed, this robot has two driving wheels, and there is a five-degree-freedom manipulator fixed on it, meanwhile, a hand with three fingers is mounted on the end-effector of manipulator.

2 Technological operations for ser vice use

To obtain autonomous locomotion control, we to do investigation on *Working plan*, *Environment recognition* and *Locomotion control.*

These three kinds of technology stated in the above are the basic technology that are needed for the autonomous locomotion control. In this paper, we develop an advanced intelligent locomotion robot by the investigation on the robot's intelligence in different levels.

3 Global Path Planning with Genetic Algorithm and Hierarchical Node Map

A. *Planning.* To get continuous autonomous locomotion control on a robot, path planning will be needed in the determination of reasonable path for the robot's working. In this re-

0-8186-7108-4/95 $4.00 © 1995 IEEE

search, the path planning is constructed on the bases of GA [3] or special environment map shown in Fig. 3a and 3b . Under the path planning, the robot's autonomous control is planed by giving command to robot with the method used in a research of man-robot-interface.

Node map is adopted in the environment map, by this method, the environment map is formed by the comparatively reliable information about work point, transit point and the line that connects the points.

Besides, the path is obtained in the form of Point-To-Point (PTP) by node map method. This kind of path form is suitable for the robot's locomotion control.

B. *Work Planning by GA.* As expressed in the above, the path is in the form of PTP. The path can be written in one dimension matrix, this kind of form is similar to chromosome. So we propose to introduce genetic operation to path population [2]. The genetic operation used in this robot is stated in below, and this algorithm is shown in Fig. 3. * Selection—roulette model strategy and elite-saving strategy; * Crossover—one-point crossover; * Mutation.

Furthermore, dispersion GA is used in this system for the avoidance of getting local solution.

There are many imaginary work for robot, in this paper, the work planning on the transport of baggage will be reported, where, the receive point and destination point (both of them are called as transit points), and weight of baggage are set in the work planning.

In the transport of baggage, the distance of path, required energy and the number of transit points in the transport work are taken as the individual factors for the estimation of this work. The fitness function used in the path planning can be expressed in the following form,

$$Fitness = \frac{K_d}{distance} + \frac{K_e}{energy} + K_t\ transit.$$

Where, to get a suitable work planning for transporting all baggage in a short time, the gains are determined from experience.

Example 1. One example about best fitness for transporting two baggage is in Fig. 4. Considered from Fig. 4 we can understand the performance for obtaining desired path from generation by GA method.

C. *Hierarchical Node Map.* Because the node map can provide reliable information to robot, the node map is suitable as environment map for this robot. There are many desired work for the robot even only in the building, in this case, the number of nodes will be quite big, therefore, eventhough GA has the ability on big global sampling, it's difficult for robot to obtain optimal solution in a short time by traditional node map method. To solve this problem, the node map is set for every work unit, and there is hierarchy for the node map.

Example 2. The HNM is formed by this method (Fig. 5). Because the work unit is divided by HNM, the unnecessary work area will be cut from the whole work area, and only the needed work area is taken for the work planning. So the work planning can be achieved easily by this method. In order to testify the proposed HNM method, work planning for baggage transport work is conducted by HNM and node map (493 total node number). The work planning is carried out in 50 times for every map, the number for obtaining the path needed in the work and the total node number for each object are shown in the Table 1 respectively. The result shows that the HNM is better than node map, and it's possible for us to use the proposed HNM in the robot's autonomous locomotion control.

4 Fuzzy control for intelligent correction of mobile robot motion

A. *Environment recognition on robot's position or posture.* Robot's position and direction related to global reference coordinate are the information for the detection of robot's posture. The robot's position related to the global reference coordinate is computed by the measured value from encoder that is fixed on the wheel. The robot's position related to the global reference coordinate can be computed approximately in the following two equaitons:

$$X_{i+1} = X_i + \frac{W(M_r+M_l)}{2(M_r-M_l)}\left\{\sin\left(\theta_i + \frac{M_r-M_l}{W}\right) - \sin\theta_i\right\},$$
$$Y_{i+1} = Y_i + \frac{W(M_r+M_l)}{2(M_r-M_l)}\left\{\cos\theta_i - \cos\left(\theta_i + \frac{M_r-M_l}{W}\right)\right\},$$

where X_i and Y_i are the robot's position related to the global reference coordinate at ith step; θ_i is robot's direction related to the global reference coordinate at ith step; M_l and M_r are wheel's movement value; W is the distance between left and right wheel.

B. *Recognition on obstacles.* To avoide the obstacle and locomote the robot, it's needed to detect the robot's posture related to the obstacle. In the robot's real time locomotion control, the detection, recognition and judgment on information are needed, so it's better for robot to use minimal but enough sensors in the system, and the handling time on the information should be short. Thus, only 5 ultrasonic sensors are used for the detection of rotot's position related to the obstacle.

C. *Locomotion control.* We can get information from the sensors fixed on the robot, for the autonomous locomotion control, it's necessary to change the detected information to recognizeable information. In our study, we propose to take fuzzy inference method for this problem.

The fuzzy inference method is also adopted for the choice of path tracking control or obstacle avoidance control.

Example 3. *Path tracking.* The locomotion control for tracking the path determined by working plan part as a connected line is conducted by the usage of fuzzy inference method. Following 4 kinds of parameters are taken as the input of fuzzy inference for the path tracking control (see Fig. 6a). 7 fuzzy levels are set for D_P, A_P and A_G, while, 4 fuzzy levels are set for D_G. Following 2 parameters are used as output of fuzzy inference: **S_T: Steering angle; **V_T: Movement speed, (7 fuzzy levels for S_T, and 4 fuzzy levels for V_T).

In our method for simplicity Mamdani fuzzy inference is used. The inference is conducted by the product of fuzzy set in the max-min form. The output control is obtained by the defuzzification of control rule with weight method.

Example 4. *Obstacle Avoidence.* The robot will avoide the obstacle according the information about the distance between robot and obstacle from environment recognition part. The input parameter is the distance information from robot to obstacle measured by sensors in the direction of left side D_{SL}, left ahead D_L, front D_F, right ahead D_R and right side D_{SR} (Fig. 6b). A layout fuzzy inference method is proposed for the obstacle avoidance control. In this method, the infered output result at this time will be used as input at next time in the fuzzy inference. By this method, the whole rule number will be decreased, and make it easy to construct a rule base.

The control rule is set in below, in the first layout, values from 5 sensors will be divided to three groups as left, center and right, by this way, the fuzzy inference is conducted.

Control ratio decision coefficient K_{OUT} is used for the determination of ratio of Path Tracking fuzzy output and Obstacle Avoidence fuzzy output in the calculation of practical control ouput. Steering angular speed S_O and robot's speed V_O are computed in equation (1) and (2).

K_{OUT} is a value changed in [0.0,1.0], and there are 4 fuzzy levels with K_{OUT}

$$S_O = k_{STR}((1.0 - K_{OUT})S_T + K_{OUT}S_A) \quad (1)$$
$$V_O = (1.0 - K_{OUT})V_T + K_{OUT}V_A \quad (2)$$

where K_{STR}– angular speed translate coefficient.

Example 5. *Simulation and Experimental results.* Simulation shows the proposed fuzzy inference method is valid in the modelling of movement environment or robot, and in the robot's locomotion control. Fig. 7a and 7b are the simulation result about path tracking control with obstacle avoidance. The robot can avoide the obstacles and move to the desired target in narrow corridor by changing the control ratio decision coefficient on the basis of obstacle's situation. The experiment on this robot is carried out in real situation by the method proposed in the above. Fig. 8a and 8b are the experiment result of path tracking control with obstacle avoidance on the corridor of building or on the floor of room. In the experiment, the obstacle is placed in the experimental surrounding, and experiment shows the robot can arrive at target by avoiding obstacle in real surrounding.

5 Conclusion

(1). To develop an intelligent locomotion robot for service use, the investigation on robot's working plan, environment recognization and locomotion control is conducted by simulation and experiment.

(2). It was investigated that for intelligent flexible control system must have hierarchical structure and 2 subsystem (global path planning on basis of HNM and GA and local for correction of trajectory basis on FC) are nedeed to introduce.

(3). By adding the necessary items to the introduced estimation fitness function and setting the suitable gains to the estimation fitness function, the robot can arrive at the desired target successfully. The simulaiton results show that the proposed HNM is effective on the reducing of work planning cost and better work planning can be achieved by this method.

(4). Development of intelligent fuzzy control system realize the human interaction between mobile robots.

References

1. Yamafuji K., Yamazaki Y., Watanabe T., Ogino K., Hamuro M. and Saeki K., Development of intelligent mobile robot for service use, Japan Soc. Mech. Engineers Ann. Conf. Robotics and Mechatronics (ROBOMEC '92)(1992), Kawasaki, Vol. B, pp. 269-270.

2. Ishikawa A., Miyagawa K., Tanaka T. and Yamafuji K., Development of intelligent mobile robot for service use, Japan Soc. Mech. Engineers Ann. Conf. Robotics and Mechatronics (ROBOMEC '94)(1994), Kobe, Vol. A, pp. 353-358.

3. Fukuda T. and Shibata T.,Integration and synthesis of neural network fuzzy logic and genetic algorithms for intelligent systems, J.Soc. Mech. Eng. (1993), Vol.59, No. 564, pp.2282-2289.

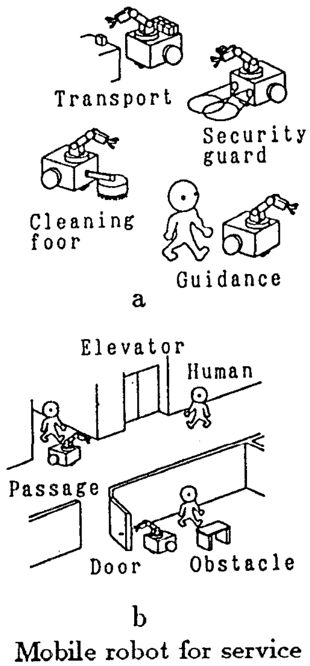


Fig.1. Mobile robot for service use
a – Structure of mobile robot for service use
b – Technological operations

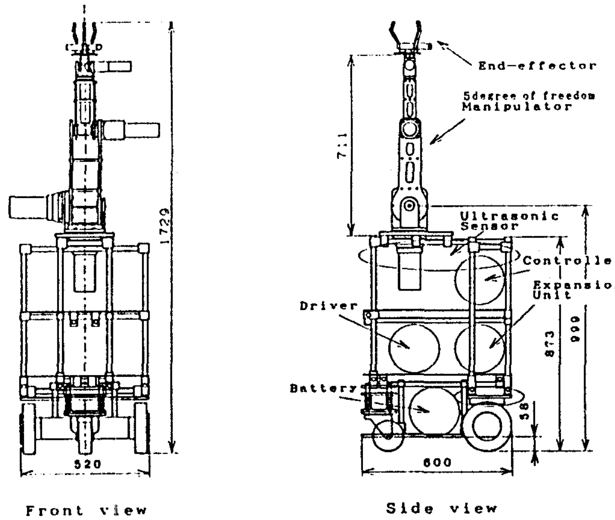


Fig. 2. Mobile robot for service use developed

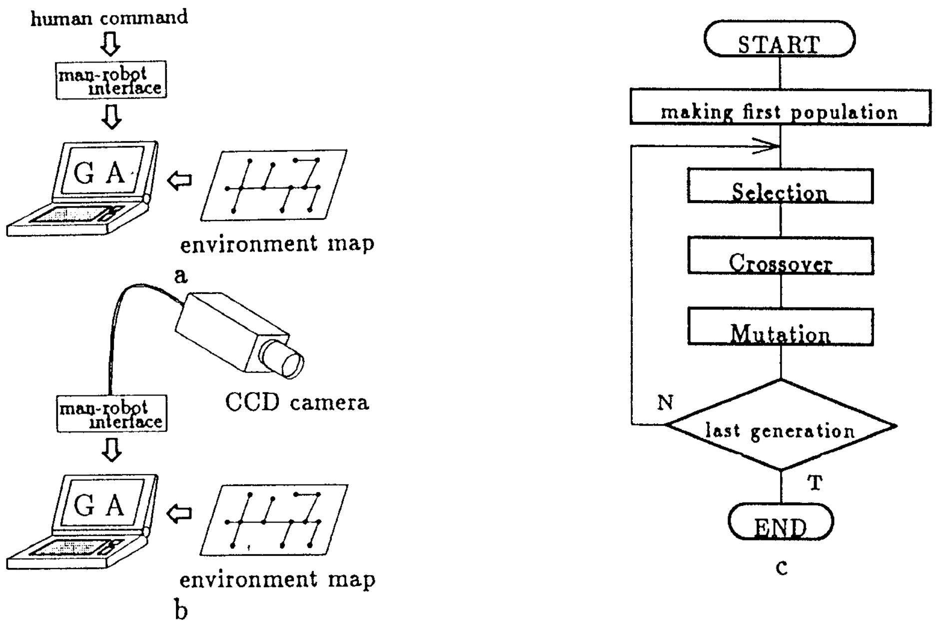


Fig. 3 Concept of Planning
a – Human robot interaction; b – Automatic path planning;
c – Block-Scheme of Genetic Algorithm

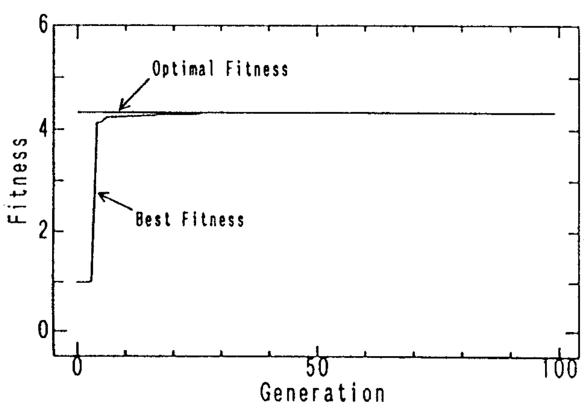


Fig. 4. Transition of best fitness

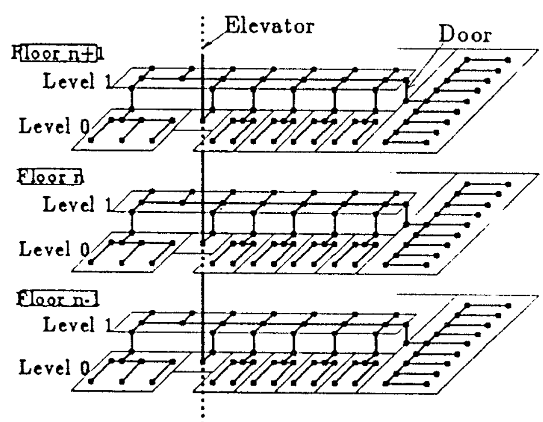
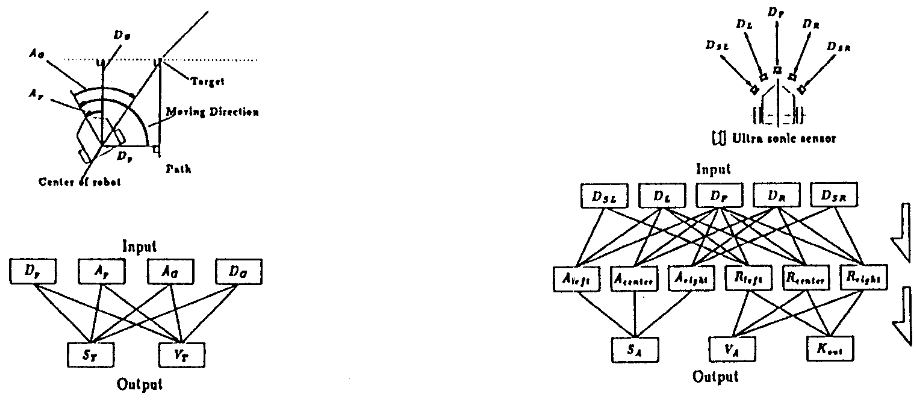


Fig. 5. HNM

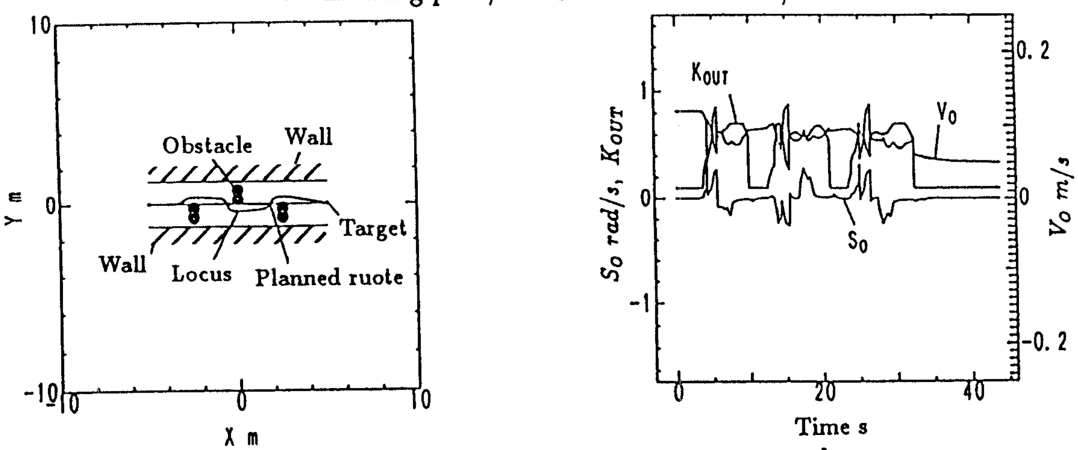
Table 1.
Difference in results between two maps

Map	Total Node	Useful
Node Map	493/493	3/50
HNM	66/493	48/50



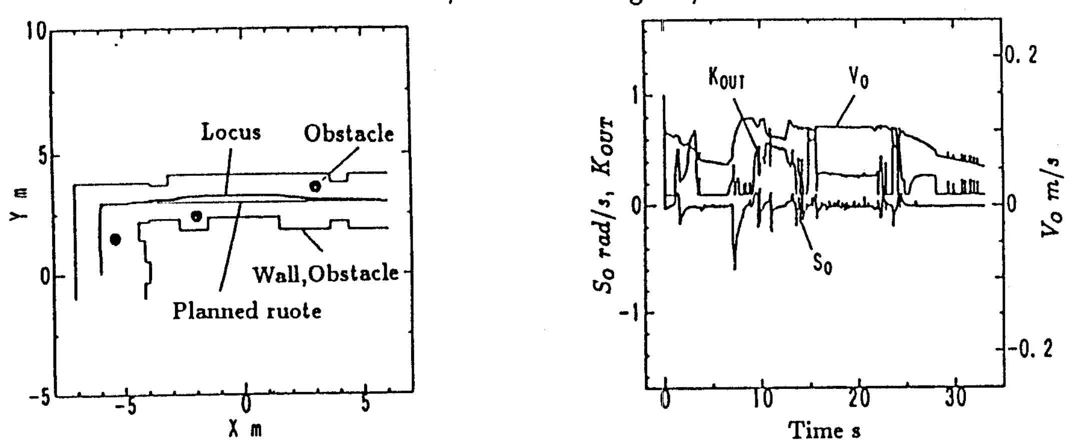
a b

Fig. 6. Structure of Fuzzy Control
a– Tracking path; b– Obstacle avoidance;



a b

Fig. 7. Simulation result
a– Locus; b– Control signals;



a b

Fig. 8. Experiment result
a– Locus; b– Control signals;