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Ultrasonic Sensor Based Navigation for a Mobile Robot Using Fuzzy Logic

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Abstract: This paper proposes ultrasonic sensor-based navigation method which utilizes fuzzy logic and reinforcement learning for navigation of mobile robot in an unknown environment. It based on the combination of elementary behaviors has been developed. Most of these behaviors are achieved by means of fuzzy inference systems. The proposed navigator combines two types of obstacle avoidance behaviors, one for the convex obstacles and one for the concave ones. The use of fuzzy inference systems to generate the elementary behaviors is quite simple and natural. However, one can always fear that the rules deduced from a simple human expertise are more or less sub-optimal. This is why we have tried to obtain these rules automatically. A new navigation method using fuzzy logic and reinforcement learning is proposed in this paper.

Keywords: Robot navigation, ultrasonic sensor, fuzzy controller, local map.

I. INTRODUCTION

Various methods for controlling mobile robot systems have been developed which are generally classified into two categories: global planning and local control. The global path planning method includes configuration space method, potential field method, generalized Voronoi diagram, and graph search method. These methods have been carried out in off-line manner in completely known environments. However, these methods are not suitable for navigation in complex and dynamically changing environments where unknown obstacles may be located on a priori planned path. Thus, the sensor-based local path planning, so called obstacle avoidance, carried out in on-line manner is required in the navigation of mobile robots. Local path planning utilizes the information provided by sensors such as ultrasonic sensor, vision, laser range finder, proximity sensor and bumper switch. It is difficult to find the force coefficients influencing on the velocity and direction of mobile robots in cluttered environments which cannot be described as a mathematical model. In order to overcome the above problem, fuzzy logic and neural network approaches have been employed in navigation of mobile robot. A new navigation method using fuzzy logic and reinforcement learning is proposed in this paper. Whenever a mobile robot navigates in uncertain environment towards the goal position, avoidance behavior and goal-seeking behavior always conflict. The avoidance behavior is used to avoid the obstacles irrespective of the goal position, while the goal-seeking behavior is used to seek the goal position irrespective of obstacle location. It is necessary for a navigator to efficiently combine two behaviors. For this, two behaviors are independently designed by fuzzy logic and reinforcement learning and are combined by the action of a switching function according to situations around the mobile robot. The fuzzy logic is used to represent the mapping between the sensor input space and mobile robot action space. The correct mapping is found by reinforcement learning. Fuzzy rule bases are built by input and output fuzzy sets which quantize the sensor input space and the mobile robot action space, respectively.

II. OBSTACLE DETECTION AND LOCAL MAP

The mobile robot has three wheels; two driven wheels fixed at both sides of the mobile robot and one castor attached at the front and rear side of the robot. In this study, twelve ultrasonic sensors are mounted around of the mobile robot in middle layer for the detection of obstacles with various heights. Fig.1 shows the arrangement of the ultrasonic sensors marked as dots in the figure. The distances e_j $(j = 1, 2, \ldots 12)$ from the origin of the robot frame {R} to obstacles detected by the sensor s_j, can be defined as $e_j = \delta_j + R_r$. Here, R_r is the radius of the robot and the δ_j, is the range value measured by the sensor s_j. A local map is introduced to record the sensory information provided by the 12 ultrasonic sensors with respect to the mobile robot frame $\{R\}$. As shown in Fig.2, a sector map defined locally at the current mobile robot frame is introduced. Then, the obstacle position vector se'_j with respect to the frame $\{R\}'$ can be calculated by

$$Se'_j = \begin{bmatrix} \cos\delta\theta & \sin\delta\theta & 0 & -\sin\delta\theta/\rho_p \\ -\sin\delta\theta & \cos\delta\theta & 0 & (1-\cos\delta\theta)/\rho_p \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

where se_j denotes the obstacle position vector defined at the frame $\{ R \}$. Hence, when the mobile robot is located at a point $0'$. the distance value $se'_j = \| se'_j \|$ from the origin of the frame $\{R\}'$ to the obstacle and angle $s\varphi'$ can be calculated by Eq.(1) . Here, ||.|| denotes Euclidean norm.

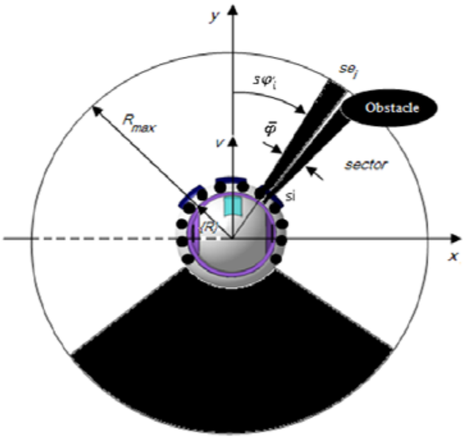


Fig. 1. The local map defined at the frame {R}

The local map defined at the frame $\{R\}'$ is newly constructed by using the previous local map defined at the frame $(R\}$ as follows:

$$Se_n \leftarrow Se'_j, n = INT(\frac{s\varphi'_j}{\bar{\varphi}}) + \frac{N}{2}; j = 1,2,\ldots, N \qquad (2)$$

Where ← and *INT* denote the updating operation and integer operation, respectively. If the range values obtained by sensors when the mobile robot is located at a point O' are e_j = (j = 1,2 ,... *12)* , the new local map is partially updated as follows :

se_j ← e_j, j = 1,2 .... *12.* The maximum range of the sonar sensor is set to be $\delta_{max} = \delta_{max} - R_r$. Any return range which is larger than is ignored.

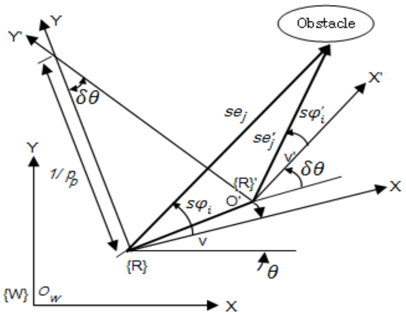


Fig. 2. The coordinate transformation for updating the local map

III. NAVIGATION OF MOBILE ROBOT

The primitive behaviors may be divided as follows: avoidance behavior and goal-seeking behavior. The output of a primitive behavior is defined by the vector

$$u(t) = (v(t), \Delta\theta(t))^T = (v(t), w(t), Tms)^T \qquad (3)$$

where t and T_{ms} denote the time step and the sampling time, respectively. Here, T denotes the transpose and $\omega(t)$ denotes the angular velocity of the robot.

In order for the mobile robot to arrive at the goal position without colliding with obstacles, we must control the mobile robot motion in consideration of the obstacle position X_{oi}, = (x_{oi}, y_{oi}) , the mobile robot position $X = (x, y)$ and its heading angle θ with respect to the world coordinate frame $\{W\}$ shown in Fig.2.

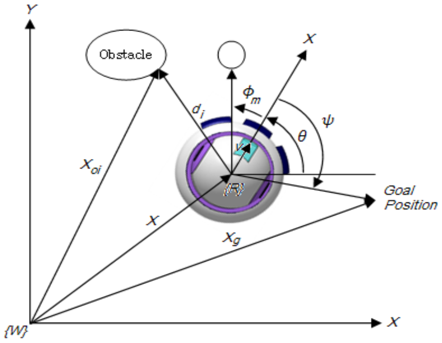


Fig. 3. The coordinate frames and control variables

In order to avoid the increase in the dimension of input space, the distance values d_i , (i = 1.2,3,4) are defined by

$$\begin{aligned} d_1 &= \min(se_1, se_2, se_3) \\ d_2 &= \min(se_4, se_5, se_6) \\ d_3 &= \min(se_7, se_8, se_9) \\ d_4 &= \min(se_{10}, se_{11}, se_{12}) \end{aligned} \qquad (4)$$

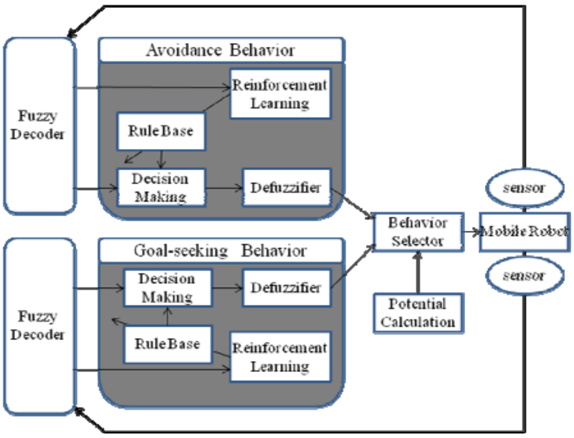


Fig. 4. The structure of the proposed navigator

The motion of mobile robot can be realized by the control of its heading velocity, v and incremental steering angle $\Delta\theta$. Thus, we choose the input variables for avoidance behavior as $d_i = \| X_{0i} - X \|, (i = 1,2,\cdots 4)$, and those for goal-seeking one as heading angle difference ψ and distance to goal, $z = \| X_g - X \|$. The output variables for two behaviors are chosen as the incremental steering angle, $\Delta\theta$ and velocity, v. The variable d_i is calculated by (Eq 4). The ψ is the angle between heading direction of the mobile robot and the direction of the goal position and the z is the distance from the current position, $X = (x,y)$ to goal position, $X_g = (x_g, y_g)$.

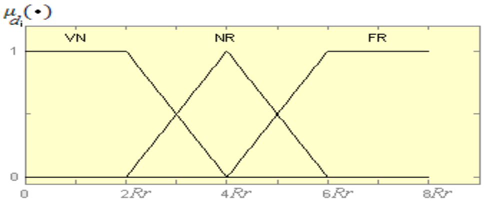
A fuzzy operator converts the crisp input data, z into the linguistic values, $\tilde{z}$ considered as labels of fuzzy sets and is defined as

$$\tilde{z} = fuzzifier(z)$$

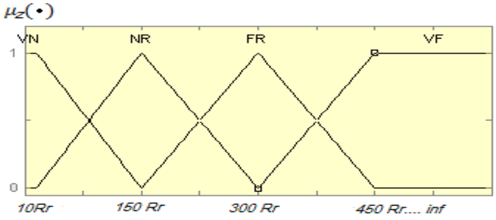
where fuzzifier denotes a fuzzification operator. From now on, tilde sign (~) representing the fuzzy set will be omitted for simplicity. The input linguistic variables $d_i (i = 1,2 \cdots 4), \psi$ and z are expressed by linguistic values (VN, NR, FR), (NB, NM, NS, ZZ, PS, PM, PB) and (VN, NR, FR, VF), respectively. The output linguistic variables v and $\Delta\theta$ are expressed by the linguistic values with membership functions having the triangular shaped functions shown in Fig. 5. Their center positions are going to be determined by reinforcement learning method. The linguistic terms have the following meanings:

Table 1. Linguistic term meanings

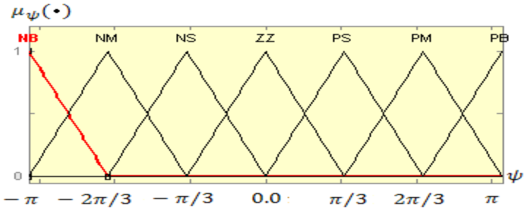
VN: very near	NR: near
FR: far	VF: very far
NB: negative big	NM: negative medium
NS: negative small	ZZ: zero
PS: positive small	PM: positive medium
PB: positive big	



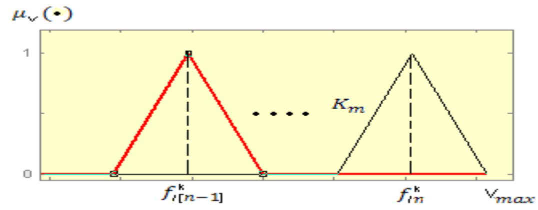
(a) The distance value of the ith sensor suit



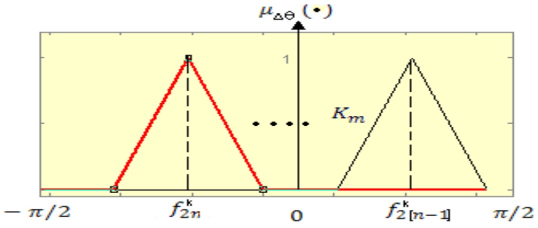
(b) The distance to goal position



(c) The heading difference ψ



(d) The linear velocity of mobile robot for the k-th behavior



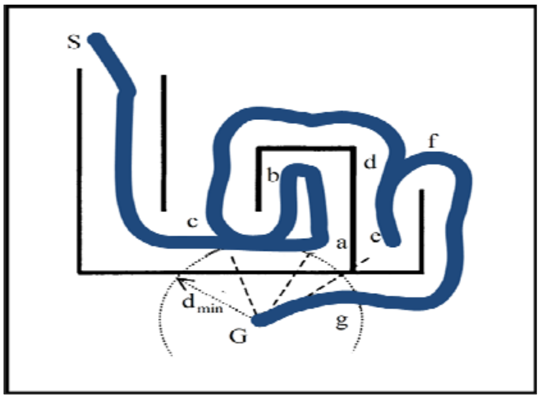
(e) The incremental steering angle for k-th behavior

Fig. 5. The membership functions of the input-output variables

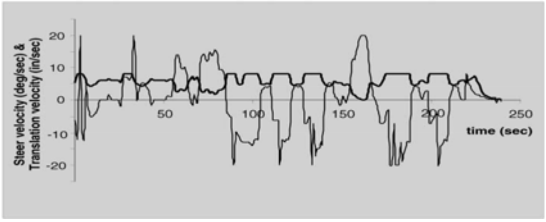
Fuzzy subsets contain elements with degree of membership, while fuzzy membership function $\mu_z(\cdot)$ of fuzzy set, z assigns a real number between 0-1 to every element in the universe of discourse.

IV. SIMULATIONS AND EXPERIMENTAL RESULTS

1. Simulations



(a) Escape from loop type and dead-end type trap



(b) Velocity (thick line) and steer velocity (thin line)

Fig. 6 Simulation for combining behaviors

Fig.6 is shown the simulation for combining behaviors. Once the rule bases for the two behaviors are completely built through reinforcement learning, the two behaviors will be combined so that the mobile robot arrives at the given goal position without colliding with obstacles. When the mobile robot navigates in a certain environment, one of these behaviors must be selected at each action step in order to accomplish its goal.

Fig. 6(a) shows the performance of the combining behaviors to escape from trap situations and go to goal. The robot first arrives by the wall-following behavior, and then enters a concave obstacle and leaves it under the avoidance of concave obstacle strategy. On the way, it encounters dead-end alleys, successfully recovers from them by avoidance behavior and eventually finds the goal under the goal-seeking behavior. The variation of the actual action decisions over time are shown in Fig. 6(b).

2. Experiment

The obstacle avoidance and goal-seeking experiments were performed in our laboratory.

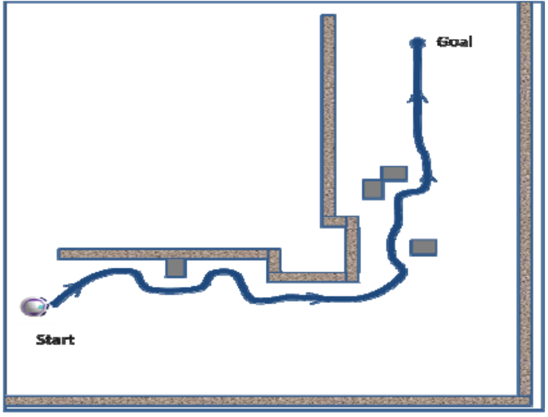


Fig. 7 Wall-following, obstacle avoidance, and goal-seeking experimental method

Fig. 8 shows the location of obstacles, the robot trajectory and its heading angle with respect to world coordinate frame when the robot travels from start position to goal position. If the robot encounters the obstacles, it avoids the obstacles by using the avoidance behavior. The behavior to be used at the present situation is selected by fuzzy decision maker. As can be seen from the figure, the robot can successfully navigate in unknown environments even if the environments are not used for constructing the rule bases of the behaviors in the simulations. This means that the robot can adapt to new environments.

1. Wall-following 2. Wall-following

3. Goal-seeking 4. Obstacle avoidance

5. Obstacle avoidance 6. Goal-seeking

Fig. 8. Experiment for combining behaviors scene

V. CONCLUSION

We have proposed the navigation system capable of performing autonomous navigation in unknown environments. In order to evaluate the performance of the overall system, a number of experiments have been undertaken in various environments. The experimental results show that the mobile robot with the complete navigation system can arrive at the goal position according to the desire even if the wheel slip occurs. From the developed of navigation system, it was observed that the mobile robot can successfully arrive at the desired position through the unknown environments without colliding with obstacles.

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