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Dynamic Path Planning Based on Fuzzy and Behavior Control Idea

Lei Yanmin[1], Xing Xiaoxue[1], Feng Zhibin[2], Guan Xiuli[1] and Du Limin[1]

[1]*School of Electronic and Information Engineering, Changchun University, China*
[2]*Electrical and Electronic Teaching and Research Section, Flight Fundamental Training Base, Changchun 130022, China*
0451lym@163.com

Abstract

In order to solve dynamic path planning problem of multi-robot systems in unknown dynamic environment, a kind of method based on fuzzy and behavior control idea was proposed in this paper. This method designs two fuzzy controllers, which are danger degree fuzzy controller and velocity fuzzy controller. They took fully into account the position and the velocity of the obstacle and the azimuth of the target. Fuzzy rules were designed based on behavior control idea and which reflected move-to-goal behavior, avoid-obstacle behavior and follow-obstacle behavior. The experimental results show that the proposed method is feasible and valid and is suitable for the dynamic and complicated environment in particularly.

Keywords: *Multi-robot systems, Dynamic path planning, Fuzzy controller, Behavior control*

1. Introduction

Many domestic and foreign scholars research path planning of multiple robot systems (MRS), especially in dynamic environment, and put forward many effective methods [1, 2]. In the path planning of MRS of the past, the information of the robot can be obtained by the implicit or communication. But in some special cases, such as communication failure or considering the safety factors, the robot has no communication each other. For a practical MRS, whether the communication exists or not, it should be able to automatically complete the navigation task. The path planning problem of no communication between the robots was studied in this paper, thus the robot must have the rapid response ability and the adaptive to the environment.

Because fuzzy logic method can well simulate the control strategy and the experience of mankind and has the robustness for the variable and unknown environment, many scholars have adopted fuzzy logic method to realize the path planning of the robot [3, 4]. On the basis of [5], the dual- layer fuzzy controller was proposed. Due to fully considering the velocity of the obstacle and the behavior control idea, the proposed method is more suitable for dynamic unknown environment and no communication of MRS.

The remainder of this paper is organized as follows: section 2 introduces the kinematics model of the tracked robot, section 3 is the design of the dual- layer fuzzy controller, section 4 is the experiment study and section 5 concludes the paper.

2. Kinematics Model of the Tracked Robot

The kinematics model of the robot is the basis of motion control. The tracked robot adopts two-wheeled differential drive mode, which may vary the motor speed of the two driving

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wheels. Thus steering of the robot can be achieved by using differential speed of the two wheels. The motion structural diagram of the robot is as shown in Figure 1 [6, 7].

(a) The position and attitude of the robot (b) The sketch map of the robot move round

Figure 1. The Motion Structural Diagram of the Tracked Robot

OXY is the cartesian coordinate system, *CXY* is the robot coordinate system, the position and attitude vector quantity of the robot is $p=(x_c, y_c, \theta)^T$, the width of the robot is D, w_c and v_c are respectively the angular velocity and the linear velocity of the robot's centroid, v_L is the linear velocity of the left wheel, v_R is the linear velocity of the right wheel.

Assumed that the wheels do pure rolling motion along a straight line on the ground, that is the instantaneous velocity of the wheel contact with the ground is zero, then:

$$w_c=\frac{v_L-v_R}{D}, v_c=\frac{v_L+v_R}{2} \tag{1}$$

Then the kinematics model of the robot is derived as follows:

$$\dot{p}=\begin{pmatrix}\dot{x}_c\\ \dot{y}_c\\ \dot{\theta}\end{pmatrix}=\begin{pmatrix}\cos\theta & 0\\ \sin\theta & 0\\ 0 & 1\end{pmatrix}\begin{pmatrix}v_c\\ w_c\end{pmatrix} \tag{2}$$

Assuming that the radius of turning circle is R, then R can be obtained according to the equation $v_c=w_cR$.

$$R=\frac{v_c}{w_c}=\frac{D}{2}\cdot\frac{v_L+v_R}{v_L-v_R} \tag{3}$$

Through analyzing (3), some conclusions are as follows:

- When $v_L=v_R$, $R\to\infty$, then the robot is moved alone straight line.
- When $v_L=-v_R$, $R=0$, then the robot is moved in-situ rotation.
- When $v_L\neq v_R$, then the robot do circle motion with the turning radius R.

When the robot move from $P(x,y,\theta)$ to $P_1(x+\Delta x, y+\Delta y, \theta+\phi)$ by Δt time interval, that is:

$$\begin{cases}\phi=w_c\Delta t\\ |PR_1|=\phi R\\ \Delta x=|PR_1|\cos(\phi/2-\theta)\\ \Delta y=|PR_1|\sin(\phi/2-\theta)\end{cases} \tag{4}$$

3. The Design of the Dual-layer Fuzzy Controller

Aiming at the problem of fuzzy rules explosion in a single fuzzy controller, the concept of hierarchical fuzzy controller was proposed in [5]. For solving the problem of path planning of MRS in unknown environment, fuzzy controller design based on hierarchical fuzzy controller, can also reduce the amount of computation and improve the real-time, so the dual-layer fuzzy controller was proposed and the architecture was shown in Figure 2.

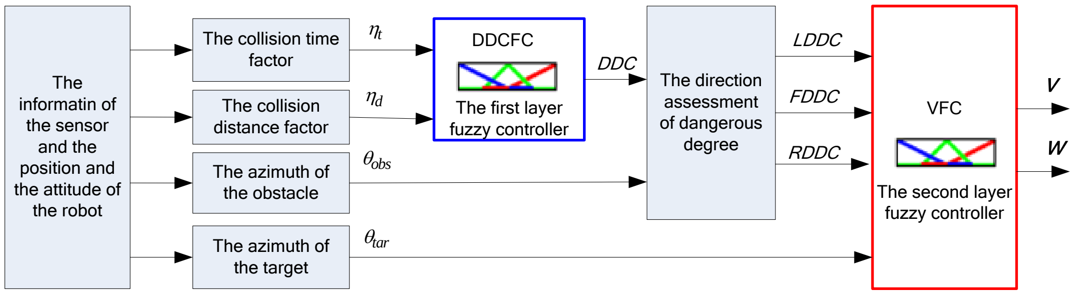

Figure 2. The Architecture of Dual-layer Fuzzy Control

The first fuzzy controller is Danger Degree of Collision Fuzzy Control (DDCFC), which deals with environment information obtained from the sense, describes the relation between the robot and the obstacle (θ_{obs}) and decides the danger degree collision that the robot collisions with obstacles (*DDC*).

The second fuzzy controller is Velocity Fuzzy Control (VFC), which determines the velocity (*v*) and angular velocity (*w*) in according to the information of the direction assessment of dangerous degree (*LDDC, FDDC* and *RDDC*) and the azimuth of the target (θ_{tar}).

3.1 The Design of Danger Degree of Collision Fuzzy Control (DDCFC)

Assuming that the robot can recognize the dynamic and static obstacles in the environment and setting the shape of obstacle is circular, the obstacle can be expressed as $O_k = (x_k, y_k, R_{O_k}, v_k, \theta_k)$. x_k and y_k are respectively horizontal and vertical coordinates, R_{O_k} is the radius of the obstacle, v_k and θ_k are the velocity and direction. The v_k and θ_k of the static obstacle are zero.

3.1.1 Some definitions: Definition 1: collision time t_{c_k}

$$t_{c_k} = \frac{D_{RO_k} - R_{rob} - R_{O_k}}{\left|V_{RO_k}\right|} \tag{5}$$

t_{c_k} is the required time that the robot collides with the obstacle. D_{RO_k} is the euclidean distance between the robot and the kth obstacle, R_{rob} is the radius of the robot, $\left|V_{RO_k}\right|$ is the relative velocity between the robot and the obstacle.

Definition 2: The collision time factor η_t

$$\eta_t = \frac{t_{c_k}}{T} \tag{6}$$

T is the sampling period. η_t means the robot will also need to go through several sampling period to collide with the obstacles. The magnitude of η_t determines the magnitude of the dangerous degree of collision (*DDC*). The smaller η_t is, the bigger *DDC* is.

Definition 3: The collision distance factor η_d

$$\eta_d = \frac{D_{RO_k} - R_{rob} - R_{O_k}}{D_s} \tag{7}$$

D_s is the smallest safety distance, η_d means the robot will also need to go through several safety distance to collide with the obstacles. The magnitude of η_d determines the magnitude of the dangerous degree of collision (*DDC*). The smaller η_d is, the bigger *DDC*.

Definition 4: The dangerous degree of collision *DDC*

DDC has several different definitions in [3, 8, 9]. According to **Definition 2** and **Definition 3**, *DDC* is defined as:

$$DDC = f(\eta_t, \eta_d) \tag{8}$$

Because *DDC* considers the magnitude and direction of the velocity of the moving obstacles, it is particularly suitable for the dynamic unknown environment.

3.1.2 Description and Fuzzification of the Input and Output Variables： From Figure 2 and **Definition 4** we can see that DDCFC has two inputs (η_t and η_d) and one output (*DDC*). Since the input and output variables are the exact quantities, and fuzzy control rules are some of the fuzzy conditional statement, so the precise quantities will be described by using vague language, that is fuzzification.

We define the range of η_t is [0,6], the fuzzy set is TS (η_t small), TM (η_t middle) and TB (η_t big), the range of η_d is [0,4], the fuzzy set is DS (η_d small), DM (η_d middle) and DB (η_d big), the range of *DDC* is [0,1], the fuzzy set is S (*DDC* small), M (*DDC* middle) and B (*DDC* big).

3.1.3 Determination of Membership Function： Types of membership functions are many, which are commonly used triangle, Gaussian-shaped, bell-shaped, *etc.*, in here each fuzzy language value adopts triangular membership function. The membership function of all variables is as shown as in Figure 3.

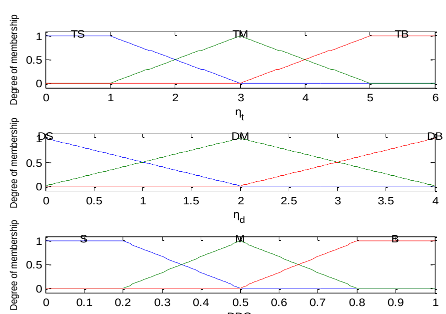

Figure 3. Degree of Membership of η_t、η_d and DDC

3.1.4 Determination of Fuzzy Control Rules： According to Definition 2, Definition 3 and Definition 4, the fuzzy control rules are shown as in Table 1.

Table 1. Fuzzy Control Rules of DDC

DDC	η_t =TS	η_t =TM	η_t =TB
η_d =DS	B	B	B

η_d =DM	B	M	M
η_d =DB	B	M	S

3.2 The Design of Velocity Fuzzy Control (VFC)

The second layer fuzzy controller is VFC, which makes the robot attain the target and avoids the obstacles in the environment. The relationship of the robot, target and obstacle is shown as Figure 4.

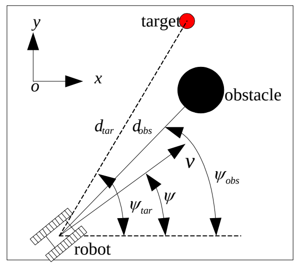

Figure 4. The Relationship of the Robot, Target and Obstacle

3.2.1 Some definitions: Definition 5: The azimuth of the target θ_{tar}

$$\theta_{tar} = \psi - \psi_{tar} \tag{9}$$

ψ is the direction angle of the robot's velocity, ψ_{tar} is the direction angle of the target. We define the target locates on the left side of the robot when $\theta_{tar} \in [-90^\circ, -30^\circ]$, the target locates on the front side of the robot when $\theta_{tar} \in [-30^\circ, 30^\circ]$ and the target locates on the front side of the robot when $\theta_{tar} \in [30^\circ, 90^\circ]$.

Definition 6: The azimuth of the obstacle θ_{obs}

$$\theta_{obs} = \psi - \psi_{obs} \tag{10}$$

ψ_{obs} is the direction angle of the obstacle. We define the obstacle locates on the left side of the robot when $\theta_{obs} \in [-90^\circ, -30^\circ]$, the obstacles locate on the front side of the robot when $\theta_{obs} \in [-30^\circ, 30^\circ]$ and the obstacle locates on the front side of the robot when $\theta_{obs} \in [30^\circ, 90^\circ]$.

θ_{tar} and θ_{obs} describe position relation and the degree of deviation which the target and the obstacle are relative to the robot.

Definition 7: The directional dangerous degree of collision

According to **Definition 4** and **Definition 6**, we can define the directional dangerous degree of collision which is respectively left *DDC* (*LDDC*), forward *DDC* (*FDDC*) and right *DDC* (*RDDC*).

3.2.2 Description and Fuzzification of the Input and Output Variables: From Figure 2 we can see that VFC has four inputs (*LDDC*, *FDDC*, *RDDC* and θ_{tar}) and two output (*v* and *w*). We define the range of θ_{tar} is $[-90^\circ, 90^\circ]$, the fuzzy set is *L*, *C* and *R*, the range of *v* is [0,0.7m/s], the fuzzy set is Z (zero), VS (smaller) and S(small), the range of *DDC* is [0,1], the fuzzy set is S (*DDC* small), M(*DDC* middle) and B(*DDC* big).

3.2.3 Determination of Membership Function: Membership function of input and output variables adopts triangular and z-shaped. The membership function of all variables is as shown as in Figure 5.

3.2.4 Determination of Fuzzy Control Rules: Based on behavior control idea, fuzzy control rules mainly follow three rules: behavior start rules, steering rules and speed rules.

Rule 1: behavior start rules

In the process of path planning the robot reflects three different behaviors: Move to Goal (MG), Avoid Obstacle (AO) and Follow Obstacle (FO). The priority of three behaviors, the highest is FO behavior, the middle is AO behavior and the lowest is MG behavior. When the two kinds of behavior also occur at the same time, first consider the higher priority behavior.

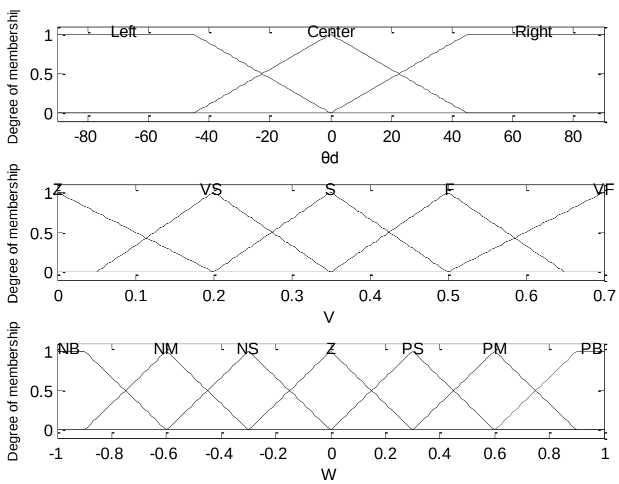

Figure 5. Degree of Membership of θ_{tar} 、 *v* and *w*

Rule 1.1: Starting FO behavior

FO behavior is the most and especially suitable for the larger obstacles. When θ_{tar} and DDC is consistent, then starting FO behavior.

Rule 1.1.1: θ_{tar} =Center and *FDDC*={M, B};

Rule 1.1.2: θ_{tar} =Left and *LDDC*={M, B};

Rule 1.1.3: θ_{tar} =Right and *RDDC*={M, B};

According to the above rules, FO behavior has 44 items fuzzy rules.

Rule 1.2: Starting AO behavior

Rule 1.2.1: θ_{tar} =Center, *LDDC*={M, B} and *RDDC*={M, B};

Rule 1.2.2: θ_{tar} =Left and *FDDC* ={M, B};

Rule 1.2.3: θ_{tar} =Right and *FDDC*={M, B}.

According to the above rules, AO behavior has 58 items fuzzy rules. Because AO behavior has 28 items fuzzy rules conflict with FO behavior, it has 30 items that was executed in fact.

Rule 1.3: Starting MG behavior

Rule 1.3.1: θ_{tar} =Center and *FDDC*=S;

Rule 1.3.2: θ_{tar} =Left and *FDDC*=S;

Rule 1.3.3: θ_{tar} =Right and *FDDC*=S.

According to the above rules, MG behavior has 18 items fuzzy rules. Because MG behavior has 7 items conflict with FO behavior and 4 items conflict with FO behavior, it has 7 items that was executed in fact.

Rule 2: steering rules

Rule 2.1: For FO behavior, the robot will turn right if it walks along on the left side of obstacles; the robot will turn left if it walks along on the right side of obstacles and the robot will turn left if it walks along the front obstacles. The size of the angle relates to *DDC*. The *DDC* is more and more bigger, then the angle is more and more bigger.

Rule 2.2: For AO behavior, the robot will walk forward and that is *w*=Z; the robot will turn left if θ_{tar} =Left, that is *w*={NS, NM, NB}; the robot will turn left if θ_{tar} = Right, that is *w*={PS, PM, PB}.

Rule 2.3: For AO behavior, the robot will turn right if $|\theta_{tar}|<|\theta_{obs}|$, the robot will turn left if $|\theta_{tar}|>|\theta_{obs}|$.

Rule 3: speed rules

Rule 3.1: For FO behavior, that is *v*={S, VS};

Rule 3.2: For AO behavior, that is *v*={S, VS, Z};

Rule 3.3: For MG behavior, that is *v*={VF, F}.

4. Experiment Study

4.1 Experiment Steps

In order to verify the proposed dynamic path planning algorithm, experiment was carried on. The steps of the algorithm as follows:

Step1: Initializing, including the number, position and velocity of the robot; start and target point; the number, position, type and velocity of the obstacle;

Step2: Judging whether the robot reaches the target, if it is the end, or turn to step3;

Step3: Calculating η_t , η_d and *DDC* according to (6), (7) and Table 1;

Step4: Calculating θ_{tar} , θ_{obs} , *LDDC*, *FDDC* and *RDDC* according to (9), (10) and **Definition7**;

Step5: Calculating *v* and *w* according to **Rule1**, **Rule2** and **Rule3**;

Step6: The robot makes a step forward according to *v* and *w*, then turn to Step2.

4.2 Experiment Results

This experiment has two robots. The robot R1 is equipped with omni-vision sensor, and it adopts triangle localization method based on omni-vision sensor. The robot R2 is not equipped with omni-vision sensor, so it adopts dead reckoning method based on photoelectric encoder. In path planning two robots get the information of the position, the velocity and the attitude angle each other by the way of wireless communication. Two robots carry through forward motion. The initial position and the goal position of two robots are S1 (0cm, 200cm), G1(400cm, 200cm), S2(400cm, 200cm) and G2(0cm, 200cm) respectively. The maximum velocity of the robot is 0.1 m/s. The sampling time *T*=2s. The sampling frame sequence of the robot's actual walking track is as shown in Figure 6, the displacement change curve of the robot R1 is as shown in Figure 7, the velocity and attitude angle change curve of the robot R1 is as shown in Figure 8 and the displacement change curve of the robot R1 .

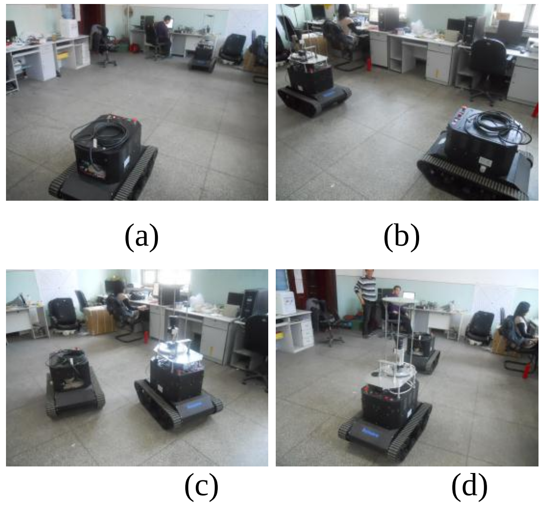

Figure 6. The Practical Scene Sequence of Path Planning of Two Robots

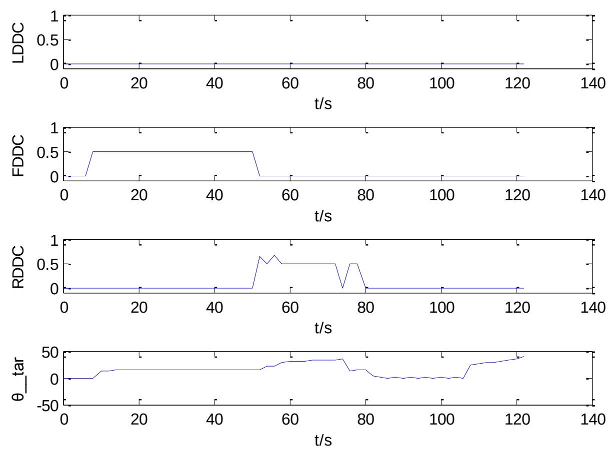

Figure 7. DDC and θ_{tar} Curve of the Robot R1

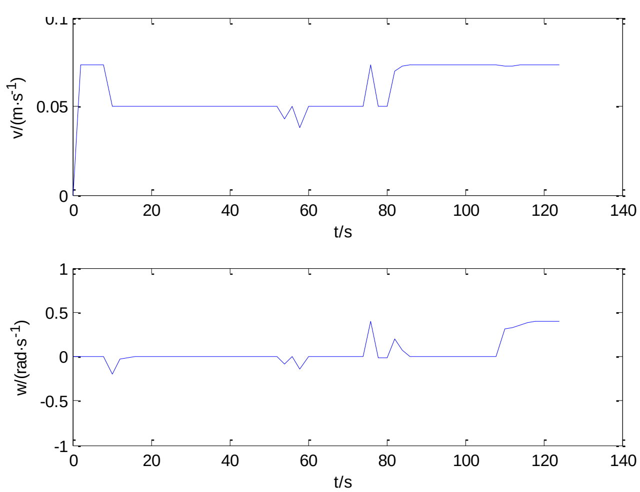

Figure 8. The *v* and *w* Change Curve of the Robot R1

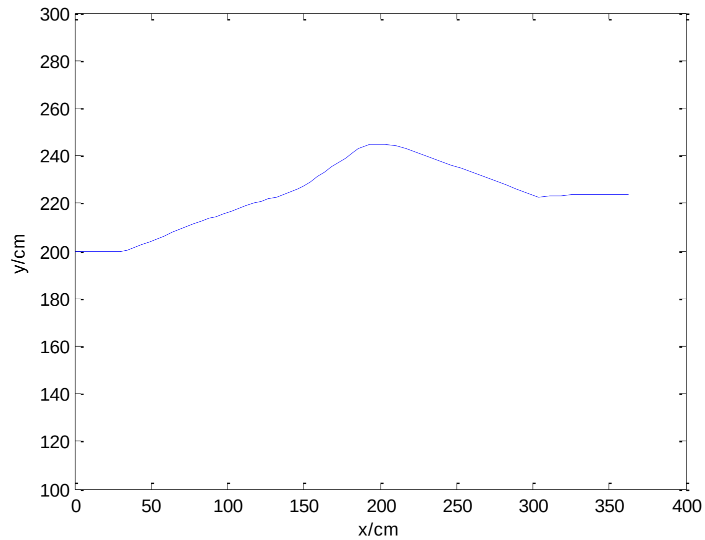

Figure 9. The Displacement Change Curve of the Robot R1

5. Conclusions

By analyzing the experimental results of Figure 6, Figure 7, Figure 8 and Figure 9, in the running process the robot is mainly reflected two behaviors: MG and AO behavior. From 50 second to 80 second the robot performs AO behavior mainly and at other times the robot performs MG behavior mainly. As can be seen from this experiment, the dynamic path planning approach based on behavior and fuzzy control is valid and feasible.

Acknowledgments

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References

[1] M. Tan, S. Wang and Z. Q. Cao, "Multi-robot System", BeiJing Tsinghua University Press, **(2005)**, pp. 1-15.
[2] S. M. Chen and H. J. Fang, "Optimal Path Planning for Dynamic Environment," J. Huazhong Univ. of Sci. & Tech., vol. 31, **(2003)**, pp. 29-31.
[3] C. T. Cai, C. S. Yang and Q. D. Zhu, „A Fuzzy-based Collision Avoidance Approach for Multi-Robot Systems", Proceedings of the 2007 IEEE international conference on robotics and biomimetics, **(2007)**, pp. 1012-1017, Piscataway, America.
[4] P. Li and S. F. Wen, "Realization of the Path Planning Algorithm Based on Fuzzy Control," Journal of Hangzhou Dianzi University, vol. 27, **(2007)**, pp. 82-86.
[5] G. S. Raju, J. Zhou and R. A. Kisner, "Hierarchical Fuzzy Control," Int J Control, vol. 54, **(1991)**, pp. 1201-1216.
[6] C. Wan, "The design of the motion control systems of the tracked mobile robot," The master degree thesis of NanJing University of Science & Technology, **(2010)**, pp. 69-72.
[7] J. H. Wang, "The local path planning and path tracking of the tracked mobile robot," The master degree thesis of NanJing University of Science & Technology, **(2006)**, pp. 10-14.
[8] Y. l. Fu, X. Y. Gu and S. G. Wang, "A Fuzzy Control Based Path Planning Strategy for Autonomous Robot," Robot, vol. 26, **(2004)**, pp. 548-552.
[9] J. Xie, W. P. Fu and J. Yang, "Obstacle-avoidance Fuzzy Control of a Mobile Robot Dased on Risk-degree of Collision," Modular Machine Tool & Automatic Manufacturing Technique, vol. 16, **(2003)**, pp. 23-25.

