Position Control for Wheeled Mobile Robots Using a Fuzzy Logic Controller

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Abstract — **This paper describes the design and development of a fuzzy logic controller for the position control of wheeled mobile robots (WMRs). The WMRs are of the type applied in Micro Robot Soccer Tournament (MIROSOT). To meet the control objective, conventional methods rely on an accurate dynamic model of the open-loop plant, as well as a well-calibrated image system. To alleviate these limitations, we propose the use of fuzzy logic controllers that incorporate expert knowledge in terms of linguistic rules. Simulations and experiments have shown that such a fuzzy controlled WMR can have a better performance than a fine-turned PD-controlled WMR.**

I. INTRODUCTION

The basic configuration of Micro Robot Soccer Tournament (MIROSOT) comprises a football stadium (ground plane) with two teams. Each team has 3 wheeled mobile robots (WMRs), a camera for image capture, a host computer and an RF data transmitter. Fig. 1 shows the system configuration.

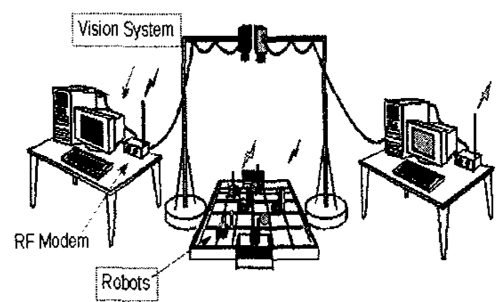

Fig. 1. MIROSOT system configuration.

The images of the WMRs in the ground plane have to be captured by the camera. These image data pass through the coaxial cable to the host computer, where the position of the WMRs are recognized and analyzed. The target position command is generated based on the current position coordinate of the WMR and the game strategy. This command is sent out through the RF transmitter. The WMR receives the command and take the response action. This action will be traced by the host computer according to the strategy until the command has been executed completely. Fig. 2 shows the block diagram of the closed-loop control system.

The problems of the control system are (i) to tackle parameter uncertainties of the system, and (ii) to obtain good WMR dynamic responses. For problem (i), if the calibration of the image system is not good, when the ground plane coordinate is mapped to the image coordinate and vice versa, the accuracy of the WMR position will be affected. The host computer may generate a wrong command signal. Moreover, we cannot find a highly accurate plant model to design the controller due to unknown factors in friction and dynamic environment.

We propose the use of fuzzy logic to incorporate expert knowledge on designing the controller. There are several advantages of using fuzzy logic controller (FLC). 1) The parameter values of the plant model need not be known exactly on designing the controller. 2) The controller can be implemented easily. 3) The computation requirement is low. 4) The response-time can be fast thanks to the nonlinear nature of FLC. This paper is organized as follows. In Section 2, the kinematics and dynamics of the WMR will be detailed. The design of the fuzzy logic controller will be given in Section 3. Simulation and experimental results will be presented in Section 4 to show the merits of the FLC as compared with a fine-tuned PD-controller. A conclusion will then be drawn in Section 5.

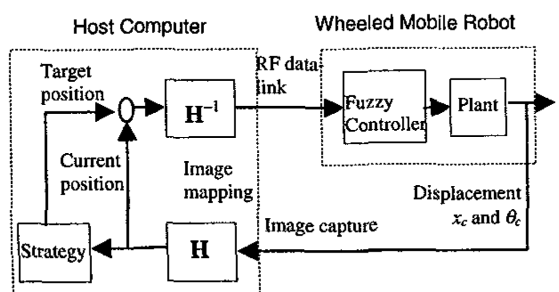

Fig. 2 Block diagram of the closed-loop WMR position control system

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II. KINEMATICS AND DYNAMICS OF WMRS

We define the WMR running on the polar coordinate system. The host computer sends two input command signals to the WMR, namely the distance between current position and target position (x_c), and the heading angle measured from the horizontal axis in counter-clockwise sense (θ_c). Fig. 3 shows the kinematic model of the WMR.

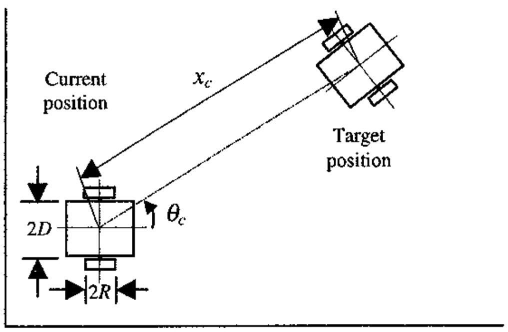

Fig. 3. Kinematics model of the WMR

The kinematics and dynamics of the WMR are adopted from [2]. The kinematic model is given by,

$$\begin{bmatrix} x_c \\ \theta_c \end{bmatrix} = \begin{bmatrix} R/2 & R/2 \\ -R/D & R/D \end{bmatrix} \begin{bmatrix} \theta_L \\ \theta_R \end{bmatrix} \tag{1}$$

where θ_L and θ_R are the angular displacement of the left and right wheels respectively. The dynamic equations of the robot system [3] are given by,

$$\theta_c(s) = \frac{R}{D}\frac{K_\omega}{s(\tau s+1)}U_{diff}(s) \tag{2}$$

$$U_{diff}(s) = U_R(s) - U_L(s) \tag{3}$$

$$x_c(s) = \frac{R}{2}\frac{K_\omega}{s(\tau s+1)}U_{comm}(s) \tag{4}$$

$$U_{comm}(s) = U_R(s) + U_L(s) \tag{5}$$

where K_ω is the static gain, τ is the time constant of the motor system, U_L and U_R are the input voltages applied to the left and right motor respectively.

A block diagram of the fuzzy logic controlled WMR position control system is shown in Fig. 4. The command signals (x_r, θ_r) will be received by the RF receiver inside the WMR. The errors (e_x, e_θ) between the command signals and the actual position, as well as the change of each error signal, are transmitted to the corresponding fuzzy controllers embedded in the WMR. The FLC outputs are the common-mode voltage U_{comm} governing the translational motion, and the differential mode voltage U_{diff} governing the rotational motion. These two signals were transformed into the individual motor input voltages (U_L and U_R) through a transformation. The angular displacements of the motors are changed into the actual distance (x_c) and angle (θ_c) through a transformation.

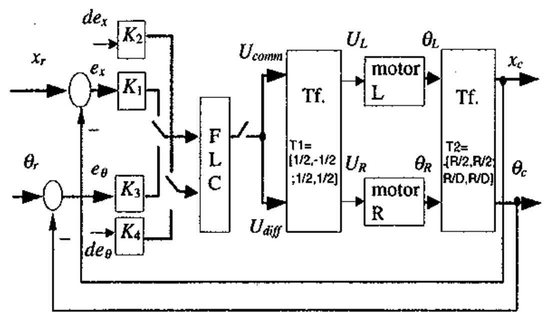

Fig. 4. Block diagram of the fuzzy logic controlled WMR position control system

III. CONTROLLER DESIGN

We use conventional fuzzy controllers that reason the inputs to outputs through fuzzification, rule inference and defuzzification. Basically, the FLC should have 4 inputs (de_x, e_x, de_θ, e_θ) and 2 outputs (U_{comm} and U_{diff}). To simplify the design, we divide the FLC into two decoupled FLCs of the same structure, and use time-division multiplex technique so that only a single 2-input-1-output FLC is needed to be implemented. The input universe of discourse differences between the two decoupled FLCs are tackled by adjusting the values of gains K_1 to K_4 as shown in Fig. 4.

A. Fuzzification:

The fuzzification procedure maps the crisp input values to the linguistic fuzzy terms with the degree of membership values between 0 to 1. We use three membership functions for both error (e_x or e_θ) and change of error (de_x or de_θ). Fig. 5 shows the input membership functions.

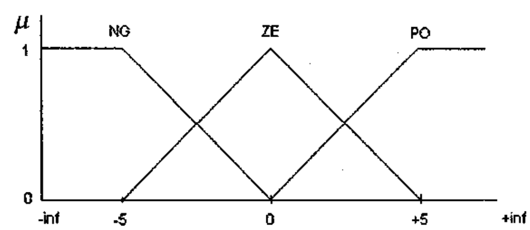

Fig. 5. Input membership functions

B. Rule Base and Inference Engine

The rule base stores the rules governing the input-output relationship of the FLC. The inference engine is responsible for decision making in the control system using approximate reasoning [4]. The operations involved are "AND" and "OR".

The control rules are designed based on expert knowledge and testing. For example, if the error is positive (PO) and is increasing (de = PO), then the motor supply voltage should be very big (VPO). Based on this knowledge, we obtain 9 fuzzy rules.

Rule 1: if e = NG and de = NG then z = VNG
Rule 2: if e = NG and de = ZE then z = MNG
⋮
Rule 9: if e = PO and de = PO then z = VPO

The fuzzy associative memory (FAM) table as shown in Table 1 summarizes the relationship between the input and output linguistic variables.

Table 1. FAM table

de / e	NG	ZE	PO
NG	VNG	MNG	Z
ZE	MNG	Z	MPO
PO	Z	MPO	VPO

C. Defuzzification

This procedure maps the fuzzy output from inference engine to a crisp signal. We use the center of gravity method to realize the defuzzification:

$$u = \frac{\int \mu \times z \times dz}{\int \mu \times dz}$$

where μ is obtained using the clipping method [5]. For each rule, this method cuts off the top of the membership function of the consequent whose value is higher than μ_i. μ is obtained by taking the union of the clipped output membership functions. The degree of membership μ_i of rule i is obtained by taking the minimum of the degree of membership,

i.e. $\mu_1 = \min(\mu_{NG}(e), \mu_{NG}(de))$
$\mu_2 = \min(\mu_{NG}(e), \mu_{NZ}(de))$
⋮
$\mu_9 = \min(\mu_{PO}(e), \mu_{PO}(de))$

All the three actions within the FLC can easily be implemented by a program in the digital computer of the WMR. Fig. 6 shows the output membership functions.

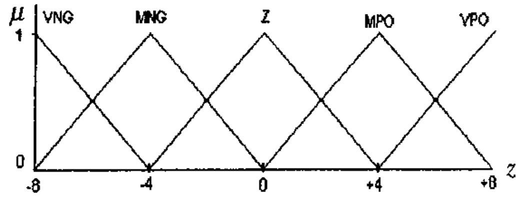

Fig. 6. Output membership functions

IV. Results

Simulations have been done to test the designed FLC. The results show that when we send the command to the WMR, the controller responsible for the angle direction drives quicker than that for the straight-line movement. The system parameters used are: R = 0.025m, D = 0.035m, K_ω= 3.6 and τ = 0.5.

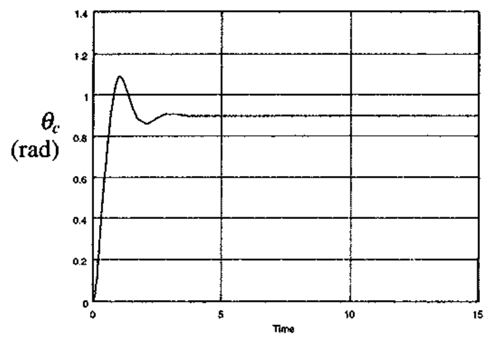

Fig. 7. Responses on using the FLC: heading angle.

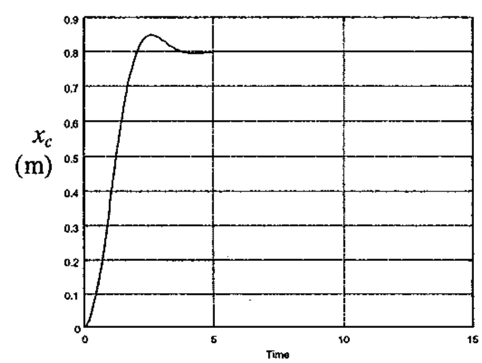

Fig. 7. Responses on using the FLC: distance

We set the current position at 0∠ 0 rad (origin) and the target position at 0.8m∠ 0.9 rad. Fig. 7(a) and (b) show the responses of the heading angle (θ_c) and the distance (x_c) on using the fuzzy logic controller, respectively. Fig. 8(a) and (b) show the corresponding responses when a fine-tuned PD controller is used. Comparing the fuzzy logic controller and the fine-tuned PD controller, we find that the fuzzy logic controlled WMR is 3 times faster than the PD controlled WMR.

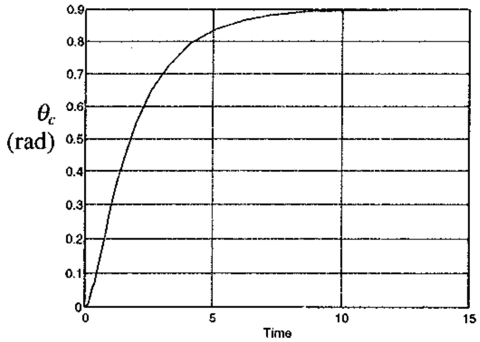

Fig. 8a. Responses on using the PD controller: heading angle.

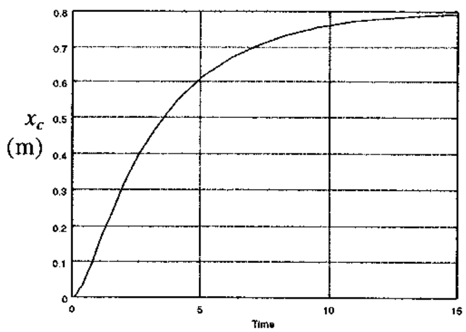

Fig. 8b. Responses on using the PD controller: distance

Experiments have been performed to verify the fuzzy logic controller design. Fig. 9 shows the wheeled mobile robot and Fig. 10 shows the displacement of the wheeled mobile robot under the fuzzy logic control. The results match well with the simulation results.

V. Conclusions

This paper reports the development of a fuzzy controller for WMRs. Thanks to the non-linear nature of the FLC, a fast dynamic response can be achieved. Without the need of relying on an accurate model of the open-loop plant, the FLC can be designed and implemented easily. The control signal can be obtained via approximate reasoning based on a knowledge base. Simulation results have been obtained and verified experimentally.

Acknowledgement

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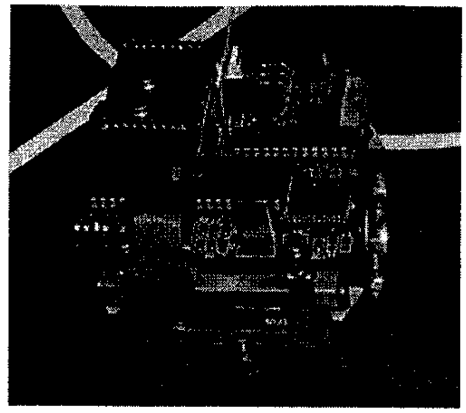

Fig. 9. Wheeled mobile robot

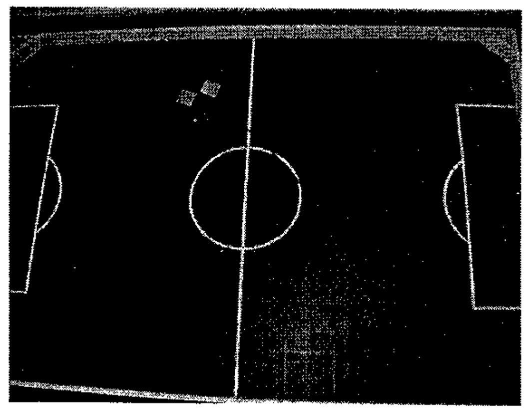

Fig. 10. Trajectory of WMR

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