이동로봇의 추적제어 및 장애물 회피를 위한 퍼지제어기의 설계

Fuzzy Logic Controller Design for Tracking Control and Obstacle Avoidance of Mobile Robot

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Abstract : We developed a FLC(Fuzzy Logic Controller) for tracking control of MR(Mobile Robot) with obstacle avoidance. In this research, we made a heuristic approach to tracking control which is simple and efficient in almost every situation using FLC. In addition, smooth turn is accomplished and also obstacles are avoided. Also we used the XX(don't care) linguistic variable for inputs in FLC to make simple rule-table. With various simulations, the validity of our FLC was shown.

1. Introduction

In mobile robot systems(Fig. 1), there are some difficulties to deal with for control. One of the difficulties lies in the fact that ordinary vehicles possess only 2 degrees of freedom (linear velocity v and rotational velocity w) for locomotion control, although vehicles have 3 degrees of freedom, x, y and ∅ in its positioning. Another difficulty is in the nonlinearity of the kinematic relation between (v, w) and (x, y, ϕ). Nevertheless, if the reference position is fixed, a simple control method is available. But when the reference position is moving rapidly, mathematical approach to control is complex and inefficient for fast tracking.

Several mathematical approaches to tracking control were found by researchers. The representative method is one by Y. Kanayama et al[1]. They proposed a stable control for determining vehicle's linear and rotational velocities (v_c, w_c) from the given velocities of the desired path (v_r, w_r). But when the linear velocity of the desired path is 0, their approach fails because they assumed the permanent motion of MR. Also, when the linear velocity of the desired path has changed abruptly there is a big overshoot. Canudas de Wit et al[5] researched about path following of MR under path and input torque constraints. In that research, the control design is based on a two dimensional dynamic model(tangential velocity and orientation) in which the system linearization, decoupling and exponential stabilization are straight forward. But there remains a problem of complexity for real-time control.

In this paper, a simple, efficient and heuristic control method is given using fuzzy logic. Fuzzy logic is very useful and effective for applications where the process is complex and ill-defined or where sensed input data needs to be interpreted qualitatively or where human experts are able to provide linguistic control rules. Also, in fuzzy logic control, multiple objectives can be reached easily by proper addition of rules[3].

With our FLC, MR can successfully keep track of the reference position which is dynamically changing by smooth turn and can also avoid obstacles nicely(Fig. 2)

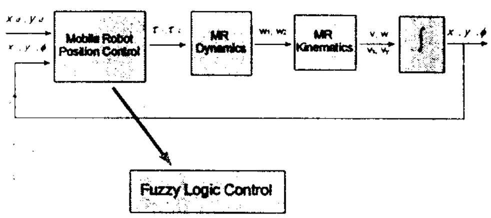


Fig. 1 Block Diagram of MR system.

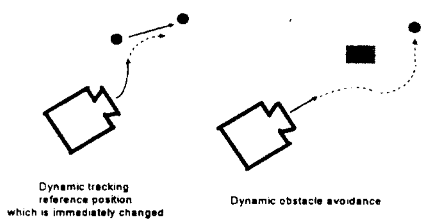
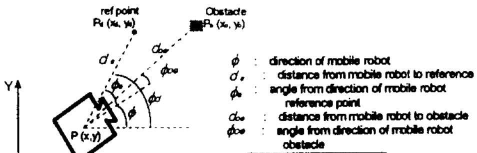


Fig. 2 Smooth turn for 2 objectives.

2. FLC for Dynamic Position Control With Obstacle Avoidance

First, let us define some parameters for errors as shown in Fig. 3. Errors from MR to reference position (d_e, $∅_e$), and errors from MR to obstacle (d_{oe}, $∅_{oe}$) will be used as input sets in FLC.



$$d_e = \sqrt{(x_d - x)^2 + (y_d - y)^2}$$
$$\phi_e = \tan^{-1}(x_d / y_d) - \phi \quad (1)$$

$$d_{oe} = \sqrt{(x_o - x)^2 + (y_o - y)^2} \quad (2)$$
$$\phi_{oe} = \tan^{-1}(x_o / y_o) - \phi$$

Fig. 3 Parameters for errors.

2.1 FLC(Fuzzy Logic Controller)

The fuzzy motion controller utilizes 4 fuzzy inputs; distance from MR to reference position, angle from the direction of MR toward reference position, distance from MR to obstacle and angle from the direction of MR toward obstacle. The fuzzification process uses 3 types of triangular membership functions(Fig. 4)

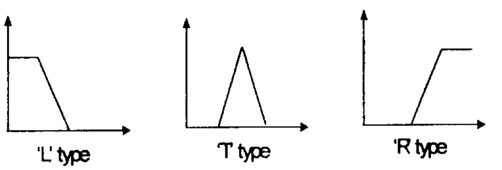


Fig. 4 3 types of triangular membership functions.

The angle measurements have 7 fuzzy terms(positive big(PB), positive medium(PM), positive small(PS), zero(ZO), negative small(NS), negative medium(NM), negative big(NB)) and the distance measurements have 4 fuzzy terms(PB, PM, PS, ZO)

A rule base of 34 rules(Table. 3) was generated based upon the first objective of tracking the reference position and the second objective of obstacle avoidance. The approximate reasoning scheme used Mamdani's method(Sup-Min) and the defuzzification was made using the COG(center of gravity)

	IF				THEN
	i1	i2	i3		o1
Ob1	PB	PB	NB/NS/ZO/PS/PB		NB/NB/NB/NB/NB
	PB	PS	NB/NS/ZO/PS/PB		NB/NB/NB/NB/NB
	PB	ZO	NB/NS/ZO/PS/PB		NB/NB/NB/NB/NB
	PB	NS	NB/NS/ZO/PS/PB		NB/NB/NB/NB/NB
	PB	NB	NB/NS/ZO/PS/PB		NB/NB/NB/NB/NB
Ob2	PB	PB	ZO		NS
	NB	PB	ZO		NS
	NS	PB	ZO		NS
	ZO	PB	ZO		NS
	PS	PB	ZO		NS

Table 1 Sample table without XX

2.2 XX(Don't Care) Linguistic Variable for Inputs

When multiple objectives , multiple inputs are used and each objective is related with separate input, much simpler rule can be made using XX which has all '1' valued membership function(This is not new one but similar to ANY in Mamdani's research). For example let's assume that

The term set of variables = {NB, NS, ZO, PS, PB}

Objective 1 : If i1 is PB, then o1 is NB

Objective 2 : If i2 is PB, i3 is ZO, then o1 is NS

Table 1 represents normal cases (not using the XX) and Table 2 represents the cases of using XX. In normal cases, even though we don't consider about the i2, i3 for the objective 1, we should fill up all 5*5=25 cases. But when using XX, we can shorten 25 rules to 1 rule like the 'Ob1' row in Table 2. Also, by letting the membership function of XX have all '1' value we can really don't care the inputs of XX when using Sup-Min approach to approximate reasoning(Fig. 5).

	IF				THE
	i1	i2	i3		o1
Ob1	PB	XX	XX		NB
Ob2	XX	PB	ZO		NS

Table. 2 Sample table with XX.

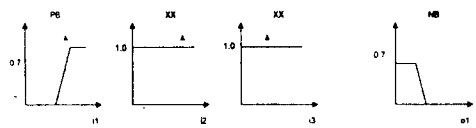


Fig. 5 Approximate reasoning with XX.

In Fig. 5, the values of input membership functions are 0.7, 1.0 and 1.0 respectively, so we take the 'Min' value between 0.7, 1.0 and 1.0 which results in 0.7 (the value of 'i1' membership function). And then, we take the lower part of output membership function than 0.7. The above process means that we don't consider 'i2', 'i3' but only 'i1'. The lower part of 'o1' membership function will be unionized with the other relations, which represents 'Sup'.

2.3 Control Rules for Tracking Control & Obstacle Avoidance

In this chapter, the 36 control rules shown in Table 3 were made for two objectives. The first objective is to track the reference position (28 rules) and the second is to avoid obstacles (8 rules). For example, for the purpose of tracking, if (d_e, $\varnothing_e$) is (PB, PB) then we should let the MR turn left rapidly, which means making the velocity of right wheel positive big and making the velocity of left wheel negative big ((w_{1ref}, w_{2ref})=(PB, NB)). When a situation of (d_e, $\varnothing_e$)=(PB, ZO) is reached with this turning motion, we should let the MR go straight rapidly, which means making the velocity of each wheel positive big ((w_{1ref}, w_{2ref})=(PB, NB)). And for the purpose of obstacle avoidance, if (d_{oe}, $\varnothing_{oe}$) is (ZO, PM) then we should let the MR turn right, which can be accomplished by (w_{1ref}, w_{2ref})=(NS, PB). In that case, (w_{1ref}, w_{2ref})=(NB, PB) can be used for turning right but this turning motion will be unnecessarily abrupt. In fact the selection of (w_{1ref}, w_{2ref})=(NS, PB) or (w_{1ref}, w_{2ref})=(NB, PB) or (w_{1ref}, w_{2ref})=(NM, PM) or etc. was determined through sufficient simulations. Alternatively, adaptive method can be used for the selection of rules.

	IF				THEN	
	d_{oe}	ϕ_{oe}	d_{ce}	ϕ_{ce}	W_{1ref}	W_{2ref}
Trackin Contro	XX	XX	PB	PB/PM/P	PB/PB/P	NB/NM/Z
	XX	XX	PB	ZO	PB	PB
	XX	XX	PB	NB/NM/N	NB/NM/Z	PB/PB/P
	XX	XX	PM	PB/PM/P	PB/PB/P	NB/NS/P
	XX	XX	PM	ZO	PB	PB
	XX	XX	PM	NB/NM/N	NB/NS/P	PB/PB/P
	XX	XX	PS	PB/PM/P	PB/PB/P	NB/NB/Z
	XX	XX	PS	ZO	PM	PM
	XX	XX	PS	NB/NM/N	NB/NB/Z	PB/PB/P
	XX	XX	ZO	PB/PM/P	ZO/ZO/Z	ZO/ZO/Z
	XX	XX	ZO	ZO	ZO	ZO
	XX	XX	ZO	NB/NM/N	ZO/ZO/Z	ZO/ZO/Z
Obstacl Avoidanc	ZO	PM	XX	XX	ZO	PS
	ZO	PS	XX	XX	NS	PB
	ZO	ZO	XX	PS/ZO/N	PM/PM/Z	ZO/ZO/PM
	ZO	NS	XX	XX	PB	NS
	ZO	NM	XX	XX	PS	ZO

Table. 3 Total rule table.

3. Simulation

3.1 Simulation Properties

The simulations were built with X window programming using MOTIF for nice graphic user interface and for displaying global motion of mobile robot. And the dynamics of MR are included to describe real moving action of mobile robot. For simplicity, only saturated velocities of motors were used without consideration of motor dynamics.

3.2 Simulation Results

Fig. 6 describes the initial state of MR, reference position(ball-shape) and the obstacle(rectangle-shape). Some of the results of simulations show the comparison of Kanayama's tracking control method and our proposed FLC method. In Kanayama's simulations, there is no action for obstacle avoidance.

Figs. 7 and 8 are the cases where the line velocity of reference position is constant, both of which show good following performances(the action for obstacle avoidance can be seen in FLC). But when the line velocity has changed abruptly or rotation velocity of the reference exist. Kanayama's method has some big overshoot(Fig. 9) and FLC shows a good following(Fig. 10).

Figs. 11 and 12 are the cases where the motion of the reference position is changed from line to circle in FLC. When the time of changing of the motion is later(Fig. 12) than Fig. 11, MR makes the obstacle avoidance of turning right for the proper tracking the reference position.

Figs. 13 and 14 are the case where several obstacles exist and where the general motion of reference position is given respectively. In both cases, FLC accomplishes a good tracking control and avoiding obstacles with smooth turn.

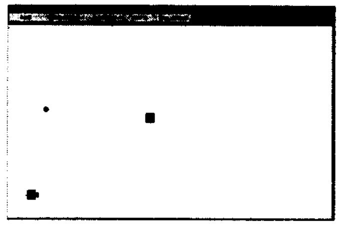


Fig. 6 Initial state.

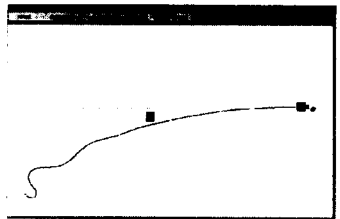


Fig. 7 Kanayama: case 1.

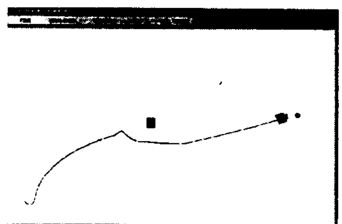


Fig. 8 FLC: case 1'.

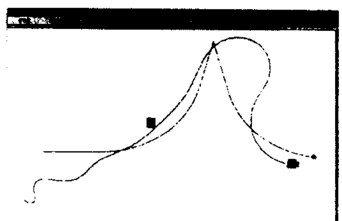


Fig. 9 Kanayama. case 2

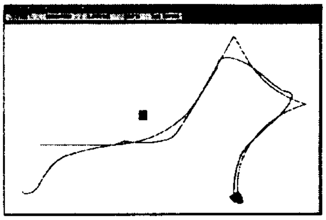


Fig. 10 FLC: case 2'.

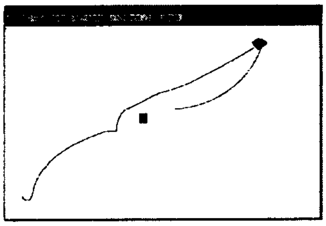


Fig. 11 FLC: case 3.

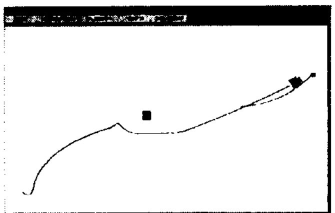


Fig. 12 FLC: case 4.

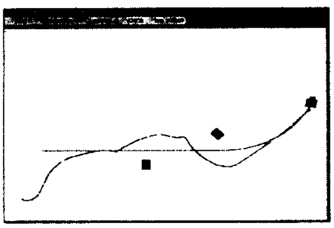


Fig. 13 FLC: case 5.

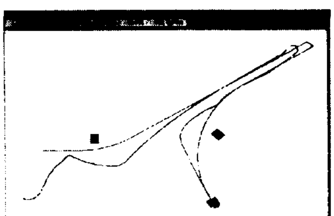


Fig. 14 FLC: case 6.

4. Conclusion

In mobile robot system, the tracking control of mobile robot is not easy because of nonholonomic property and nonlinear property. Furthermore, when the reference position is changing abruptly the existence tracking control methods are some complex and inefficient for fast tracking. In this research, a simple and efficient FLC for tracking control of mobile robot with obstacle avoidance was proposed. And the rules for the two objectives could be described as simpler form using XX(don't care) linguistic variable for inputs. With various simulations it is seen that the two objectives were satisfied by smooth turn.

In further works, there needs more sophisticated selection of rules. It can be achieved by adaptive approach for making output rules. XX for outputs having all '0' valued membership function can be used In multi-agent system, if the proper generation of reference position will be done by FLC and combined with the results of this research, then it will be a good control system for multi-agent control problem.

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