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PATH FOLLOWING CONTROL OF AUTOMATIC GUIDED VEHICLE BASED ON HIERARCHICAL FUZZY ALGORITHM

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ABSTRACT

A three-wheel AGV with front wheel steer and rear wheel drive is taken as the research objective.On the basis of establishing the hardware framework of the motion control system,the software design of PMAC under the environment of VC++ is discussed relevantly.At the same time,a hierarchical fuzzy algorithm is introduced in the path following of the AGV. Having applied hierarchical fuzzy systems in the control architecture, the number of rules in a fuzzy controller was reduced greatly. A robust control term was used to compensate the approximation error of fuzzy systems, which could reduce the effect on tracking accuracy caused by the error. It was proved that the tracking error converged to the small neighborhood of zero, and the tracking error could be decreased by enlarging parameters in the robust control term. The test results verified the efficiency of the hierarchical adaptive fuzzy controller.

Keywords: *Automatic Guided Vehicle (AGV), Hierarchical fuzzy control, path following, PMAC*

1. INTRODUCTION

With the development of auto industry, research of Automated Guided Vehicle(AGV) is already growing in popularity . The AGV refers to the traveling bogie with electromagnetic or optics performance which can automatically drive and follow an expecting path.At the same time ,the AGV has programming unit and safety device.It is a key device of modern material flow system.[1] The performance of AGV is mainly represented in motion control.Generally speaking,the AGV's velocity fluctuation is realized by means of changing the voltage of its driving motor.At the present time,the common ways of AGV's motion control, including DC motor speed-regulating system and photoelectric encoder based on thyristor and self-turn-off device, are often used .And sometimes the motion control also can be realize by PLC.[2]Although these methos seem simple,the tracking accuracy is not high due to the accumulative error which produced while the AGV walks continually.Meanwhile, a fuzzy self-adaptive PID control scheme is developed by many scholars.Commonly,we should compare the current state(x,y, θ) of the AGV with the reference state(x_{ref}, y_{ref}, $θ_{ref}$)to know the state bias information(e_x , e_y, $e_θ$),so we can use the asymptotic stability rule to control AGV's real motion state.The fuzzy self-adaptive PID control has the preferable robustness and anti-jamming as well as small short overshoot,good performance and fast response.[3]But,the amount of fuzzy control rule is an exponential function of system variables.So the fuzzy rule items are too many.In this paper,a robust indirect adaptive control scheme is developed to follow the desired geometric path. The outstanding merit is that whose amount of rule greatly reduced.

2. AGV'S MOTION CONTROL SYSTEM

2.1 Establishment of Mathematical Model

The AGV's mathematical model is shown as Figure 1.

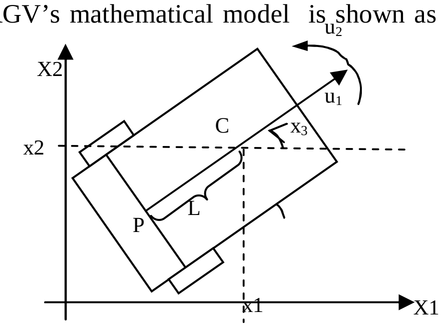

Figure 1. Diagram Of AGV's Motion Model

Where(x_1,x_2)denotes the AGV's mass centric coordinates in rectangular cartesian coordinate system. x3 is its attitude angle. L denotes the vertical distance between the AGV's center of mass and its axle. We assume that L is positive when center of gravity is ahead of the axle,otherwise L is considered as negative. u1 denotes the speed of the

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centerline of axle while u2 is angular speed of attitude angle.So,the AGV's motion mathematical model can be described as:

$$\begin{cases} \dot{x}_1 = u_1 \cos x_3 - L u_2 \sin x_3 \\ \dot{x}_2 = u_1 \sin x_3 + L u_2 \cos x_3 \\ \dot{x}_3 = u_2 \end{cases} \quad (1)$$

Assume that the AGV is characteristic of nonskid stop in the Lateral direction.That is to say, the speed of axis direction of driving wheel is zero.with that, we have

$$x_2 \cos x_3 - x_1 \sin x_3 = 0 \quad (2)$$

Eq.(1) indicates that the AGV's nonholonomic constraint can be obtained from Eq.(2). So,the problem of path following can be proposed as: giving the desired geometric path as h(x1,x2)=0,then seeking the feedback control law which is written as u=u(x1,x2,x3),finally, the AGV's mass center curve can be slowly closed to the desired geometric path by means of adjusting corresponding parameters.[4] This paper mainly research the path following problem when its mass center is unknown nonzero constant.The control issue of an uncertain system adopts self-adaptive fuzzy method.The design of AGV's fuzzy controller adopting hierarchical fuzzy system has a good characteristic,the amount of the control rules is a linear function of the system variables,thus an efficiency approach is proposed for this problem.

2. 2 System Hardware Platform

The hardware platform of the designed system is mainly consist of PMAC(Programmable Multi-Axes Controller) control board,amplifier,DC servo motor and industrial computer.PMAC proposed by Delta Tau Corporation in the 90s of the century,a kind of open multiple axes controller, is designed to provide some basic functions such as motion control,discrete control and the interaction of the host.There is a Motorola DSP 56001 digital signal processing chip in internal PMAC whose index like speed,resolution ratio,band width,etc are far superior to that of general controller.Because PMAC is suitable for complex control,it is widely use in robot control.[6]The principle diagram of the motion control based on PMAC is shown as

2.3 System software solutions

When walking,through adjusting the speed of AGV's two diving wheels,the path following control can be done smoothly.[5] Supposing that the speed of the left wheel is v_1 while the right one is v_2,when Δt tends to zero,the vehicle's walking speed can be represented by $v=(v_1-v_2)/2$. When $\Delta v = v_1-v_2$ takes different values corresponding to different walking state of the AGV As shown in Table 1.

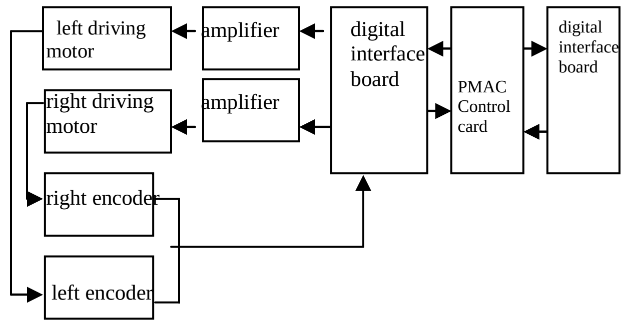

Figure 2. Diagram Of PMAC's Control Principle

Table 1. The Walking State Of AGV

Δv	Walking state
0	the straight line
>0	Walk to right
<0	Walk to left

The controlling software send on-line instructions in order to control the running speed of driving motor. When the AGV has different walking state,firstly the software may inquire the control rule set,then adopt the corresponding control commands. Therefore,the AGV's path accurate tracking can be achieved. The sample code is shown as below.

```
//stop #1,#2 motor
PmacGetResponseA(0,buf,255,"#1k#2k");
//set the speed as 10m/s
PmacGetResponseA(0,buf,255,"i122=10i222=10
");
//start walking
PmacGetResponseA(0,buf,255,"#1j+#2j+");
```

3. AGV'S TRACKING CONTROL EXPERIMENT

3. 1 Design of path tracking Controller based on Hierarchical fuzzy systems

In order to test the effect of AGV's path tracking,we take into account a circular free curve as desired reference pathing and lay a black ribbon.The walking speed is set as 0.1m/s. Owing to the performance difference of the motor, roughness of the surface,etc.

It is hard to describe by an accurate mathematical model.Here, a hierarchical fuzzy control strategy is

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proposed to path tracking.[7]As is shown in Fig.3,give a hierarchical fuzzy system construction with n layers. The variables of x_1 , x_2 is input to the first layer fuzzy system while its output y_1 and another variables x_3 is input to the second layer.And so on,for this hierarchical fuzzy system,it is proved to be optimal in the sense of least amount of rules.

Figure 3. A hierarchical fuzzy system with n inputs

If the given desired path equation $h(x_1,x_2)$ exists continuous partial derivative $\boldsymbol{h}_{x_1}$, $\boldsymbol{h}_{x_2}$. We assume that the AGV walks at the desired speed of ud(t).So we believe its real speed u_1 = ud(t). the speed can be defined as $v=h(x_1,x_2)$.Using it yields:

$$\begin{aligned}\dot{v} &= u_1(h_{x_1}\cos x_3 + h_{x_2}\sin x_3)\\ &+L(h_{x2}\cos x_3 - h_{x_1}\sin x_3)u_2 \\ &= f(x_{1,}x_{2,}x_3)+g(x_{1,}x_{2,}x_3)u_2\end{aligned} \quad (3)$$

Thus,the problem of the geometric path tracking discussed above can be considered as the design of u_2 to make the variables v in formula (3) towards zero. With respect to a certain controllable region $U_c \subset R^3$, existing a variables x in it,the controllable condition of system (3) can be specified as g(x)≠0.Here, $tgx_3 \neq h_{x_2}/h_{x_1}$ .It is clear that the AGV's walking direction is not a parallel with normal direction of desired path. Note that $\phi = x_3 - \alpha_t$,where $\alpha_t = a\tan 2[h_{x_1}/(-h_{x_2})]$,the control problem is to guarantee that in the limit as $h(x_1,x_2)\to 0$, α_t is regulated to the desired path 's tangent direction of order(x_1 , x_2). For all initial conditions $x_3 \in [0, 2\pi)$, $\alpha_t \in [0,2\pi]$,we discuss the design method of controller while $\alpha_t = a\tan 2[h_{x_1}/(-h_{x_2})]$ mainly,here,

$$f_0 = (h_{x_1}\cos x_3 + h_{x_2}\sin x_3) = -\sqrt{h_{x_1}^2 + h_{x_2}^2}\sin\phi \quad (4)$$

$$g_0 = (h_{x_2}\cos x_3 - h_{x_1}\sin x_3) = -\sqrt{h_{x_1}^2 + h_{x_2}^2}\cos\phi \quad (5)$$

$$\phi = \frac{Pu_1 + (-LQ + h_{x_1}^2 + h_{x_2}^2)u_2}{h_{x_1}^2 + h_{x_2}^2} \quad (6)$$

where $h_{x_1}^2 + h_{x_2}^2 \neq 0$

$$P = (h_{x_1x_1}h_{x_2} - h_{x_1x_2}h_{x_1})\cos x_3 + (h_{x_1x_2}h_{x_2} - h_{x_2x_2}h_{x_1})\sin x_3$$

$$Q = (h_{x_1x_1}h_{x_2} - h_{x_1x_2}h_{x_1})\sin x_3 - (h_{x_1x_2}h_{x_2} - h_{x_2x_2}h_{x_1})\cos x_3$$

define $d = \inf\{|h(x_1,x_2)| : h_{x_1} = h_{x_2} = 0\}$ and there exist strictly positive constants $\varepsilon(0<\varepsilon<\pi/2)$, the AGV's walking boundary is shown as Fig 4 and should guarantee g(x)≠0, The following gives a design scheme of hierarchical fuzzy indirect adaptive controller.

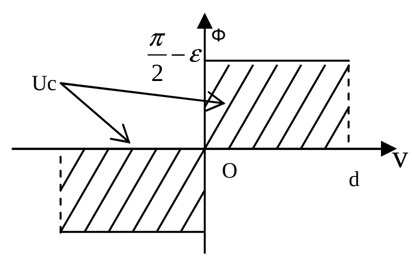

Figure4.Controllable Region

We use two layers of fuzzy logic system $\hat{g}(x|\theta_g)$ to approximate to an unknown function g(x).In the design x_1,x_3 is well defined for the first layer inputs,meanwhile the first layer's output $z_1 = \theta_{g,1}^T\xi_1(x_1,x_3)$ and x_2 is defined for the second layer inputs whose output is $\hat{g}(x|\theta_g) = \theta_{g,2}^T\xi_2(z_1,x_2)$,the design model is given by:

$$u_1 = \begin{cases} u_d(t), & \text{while } v\neq 0 \text{ and } 0<\mathrm{sgn}(v)\phi<\pi/2-\varepsilon \\ & \text{or } v=0 \text{ and } |\phi|<\pi/2-\varepsilon \\ 0, & \text{while } v\neq 0 \text{ and } \mathrm{sgn}(v)\phi = \pi/2-\varepsilon \\ & \text{or } v=0 \text{ and } \phi = \pm\pi/2\mp\varepsilon \\ u_1 = (-(h_{x_1}^2+h_{x_2}^2)u_2 + \mathrm{sgn}(v))/P, & v\neq 0 \text{ and } \phi = 0 \end{cases} \quad (7)$$

$$u_2 = \begin{cases} u_c + u_r + u_s, & v\neq 0 \\ -c\,\mathrm{sgn}(\phi), & v=0 \text{ and } \phi = \pm\pi/2\mp\varepsilon \end{cases} \quad (8)$$

Where c is a positive constant, fuzzy control item is given by:

$$u_c = \frac{1}{\hat{g}}[-f + s_0 v], s_0 < 0 \quad (9)$$

The robust control item is given by:

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$$u_r = -\frac{\beta}{\alpha g_L} v. \tag{10}$$

affords compensating error, Where, $\alpha, \beta > 0$ .And selecting of α ,where $\alpha + s_0 < 0$,is used to supervise the control item.

3.2 Experiment result and analysis

Using the above control scheme,with the desired circular path given,this paper designs the controller and do experiment as follows:

A circle equation is defined as $x_1^2 + x_2^2 = r^2$.So the desired value is formularized as：

$v = h(x_1, x_2) = x_1^2 + x_2^2 - r^2$,where

$\phi = x_3 - a\tan[\frac{x_1}{-x_2}], d = r^2$

$f_0 = 2(x_1 \cos x_3 + x_2 \sin x_3) = -2\sqrt{x_1^2 + x_2^2}$

$g_0 = 2(x_2 \cos x_3 - x_1 \sin x_3) = -2\sqrt{x_1^2 + x_2^2}$

Obviously,the curve h（x_1, x_2） satisfies the above theorem. The fuzzy controller adopts two layers of fuzzy system. Iputs of the first layer is x_1， x_3 while its output is $z_1 \geq 0$. Iputs of the second layer is z_1 , x_2 ,where N_2 = 3.Three fuzzy sets is defined in the domain of x_1 , x_2 , three in the domain of z_1 and four in the domain of x_3. Hence, the number of rules of two layers is twenty-one. We only need to adjust twelve parameters of the second layer of the fuzzy system.Whereas ,if we use the traditional fuzzy system we should pay attention to thirty-six rules and adjust much more parameters. So,the designed scheme make computation greatly reduce and improve the control efficiency.

In experiment, let $(x_1^0, x_2^0, x_3^0) = (1.1, 0.1, 7\pi/6)$, adjusting- parameter $\beta_2 = 1$ and let

$$s_0 = -0.3, \alpha = 1, \varepsilon = 0.1, \beta = 0.01$$

In path following experiment,the AGV acquires the road information through visual sensor CCD. In order to grasp the current orientation relative to its navigation path of motion.As is shown in Fig.5, the AGV's real walking curve relative to the navigation path can be seen clearly by VC++6.0. As can be seen from the figure,there exists certain deviation at the start.Slowly,the deviation tends to a tiny set value.[8] The experimental results show that the controller design based on two layers fuzzy system owing their better accuracy and stability.

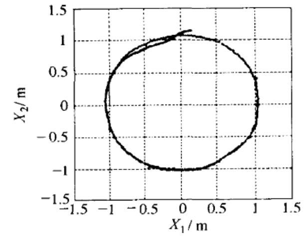

Figure.5：Experiment Result

because any nonlinear path can be approached by the line or arc,so ,for any desired path,once its equation satisfies the initial condition (1) and (2) of the theorem, the path following scheme of self-adaptive fuzzy controlling in this paper can be adopted.

4. CONCLLUSION

In this paper we introduce a kind of AGV's motion control scheme based on hierarchical fuzzy system. This method is strictly proven in theory to be efficient . It can be developed to follow the desired geometric path ,which removed the possible controller singularity and ensured the desired direction of the path.Also having applied hierarchical fuzzy systems in the control architecture ,the number of rules in a (standard) fuzzy controller was reduced greatly.

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REFRENCES:

[1] Liao Huali, Zhou Xiang, Dong feng, “AGV navigation alogorithm based on fuzzy control”, *Journal of Harbin Institute of Technolog, Vol 37, No.7, 2005, pp.40-43*.

[2] Liu Quan, Yin Aihua,”the realization of motion control of intelligent mobil robot based on PLC”, *Journal of Electro-Mechanical Engineering, Vol 20, No.1, 2004, pp.60-62.*

[3] Baogang Hu, George K I Mann.Raymond G Gosine.”A systematic study of fuzzy PID controllers-function-based evaluation approach”, *IEEE Transactions on Fuzzy Systems.Vol.7, No.5, 2001, pp.699-712*.

[4] Encaacao, P., Pacoal, A., & Arcak, M. (2000).”Path following for autonomous marine craft.” *Proceedings of IFAC conference on manoeuvring and control of marine craft (pp. 117－122).*

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[5] Widrow B, Stearns S.D, "Adaptive Signal Processing", *Engle Wood Cliffs, NJ: Prenticer Hall, 1985*.

[6] DELTA TAU Data System Inc."PMAC's MANUAL".*USA: DELTA TAU Data System Inc, 1998*.

[7] Sun Duoqing,Huo Wei,Yang Xiao.,"Path Following control of mobil robosts with model uncertainty based on hierarchical fuzzy systems", *Journal of Control Theory & Applications, , Vol 21, No.4, 2004, pp.489-495*.

[8] WANG Lixin.," adptive fuzzy system and control design and stability analysis" *Beijing: National defence industry Press, 1995:120-163*.