International Research Journal of Engineering Science, Technology and Innovation (IRJESTI) (ISSN-2315-5663)
Vol. 2(4) pp. 57-64, July, 2013
Available online http://www.interesjournals.org/IRJESTI

Full Length Research Paper

Fuzzy Control of AGV Based on Vision Based in Path Tracking

***2Jiangwei Chu, 1Hongliang Li, 3Pengfei Cui, 4Tiangang Qiang, 5Liu Ruijun**

1,2,3,4 Transportation College, Northeast Forestry University, Harbin, China
*Corresponding Author E-mail: cjw_62@163.com

Accepted 26 June, 2013

The development of techniques for lateral and longitudinal control of vehicles has become an important and active research topic in the face of emerging markets for advanced autonomous guided vehicle (AGV). Considering an AGV is nonholonomic dynamic system with inherent nonlinearity, unmodelled disturbance and unstructured unmodelled dynamics, fuzzy logic system based control is appropriate. This paper presents a microcontroller implementation of a fuzzy control algorithm applied to the developed AGV platform. The method utilizes fuzzy control theory to obtain the appropriate steer angle through posture errors consisted of position error orientation error by selecting optimal parameter of fuzzy logic controller. The kinematic model of differential-drive AGV is presented in order to simulate the robustness of the controller. The proposed schemes have been implemented in both simulation and experimentations with a real AGV platform, and the results provide satisfactory tracking performance for the vision-based navigation of AGV.

Keywords: Embedded fuzzy logic control, Vision-based Autonomous Guided Vehicles, Path tracking, Differential drive.

INTRODUCTION

Recently, with the advances in sensors and microelectronics, researchers are being to focus on AGV equipped with more intelligent capabilities such as learning from environment and performing automatically. Now, AGV are mainly applied in many industries, i.e., automotive, manufacturing, distribution pharmaceutical (Chu et al., 2002; Romuald and Roland, 2002; Yang, 2006; Chen et al., 2006). In recent years, theoretical developments of fuzzy control have been proposed, and the constructions and the uses of fuzzy controllers have been explored (El-Hajjaji and Bentalba, 2003). AS is one of intelligent wheeled mobile robots (WMR), the motion control of AGV is the very heart of any robotic systems and essential to build robust and interesting behavior. AGV is characterized by highly nonlinear and complex dynamics, adventitious forces, such as those due to head winds, turning and static friction, typical of harsh outdoor environments, further complicate the modeling process model parameters (Kodagoda et al., 2002). Even if the model and the parameters are known accurately for an AGV, there are the road grade changes and variations in the amount of cargo in the AGV that need be accounted for. Thus any control strategy to be useful for outdoor AGV control must be able to deal with the above effectively.

Many control strategies have been proposed to solve this problem: the application of linear feedback control methods has been common as evident from the references (Kamga and Rachid, 1996; Zalila et al., 1998; Hunt et al., 1998).). Most commonly used linear control techniques for AGV control are proportional integral (PI) (Kamga and Rachid, 1996; Zalila et al., 1998), proportional derivative (PD) (Kamga and Rachid, 1996) and proportional integral derivative (PID) (Hunt et al., 1998). Some researchers in Kanayama and Yuta, 1988 and Amidi, 1990 presented predictive control method and neural network algorithm control method, and successfully implemented their schemes in simulation. However, AGV highly nonlinear, making these intelligent controllers proposed and implemented lacking stability in sudden change of path direction specially.

The complexity of the AGV dynamics, the difficulty of obtaining the actual vehicle dynamic parameters, the variability of certain model parameters and the human-knowledge available on speed and steering

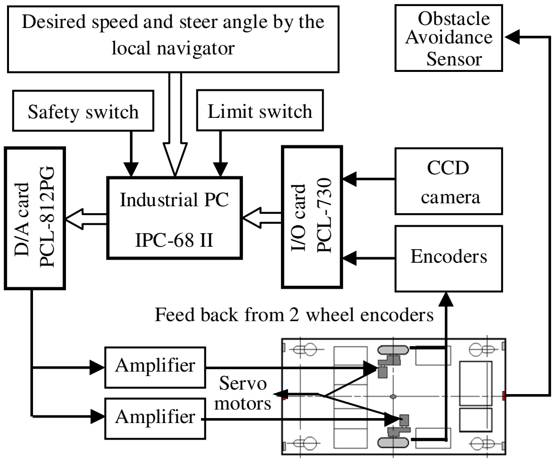


Figure 1. The experimental system

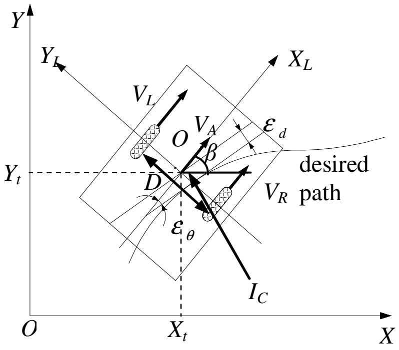


Figure 2. Kinematic model of the AGV

control motivates the use of a fuzzy logic in this paper. Originally advocated by Zadeh 1965, fuzzy logic has become a mean of collecting human knowledge and experience and dealing with uncertainties in the control process. Fuzzy logic control is the most useful application to a variety of industrial systems from its design simplicity, its implementation, and its robustness properties by far. Furthermore, fuzzy logic control is also capable of handing the substantial nonlinearities found in robot dynamics.

This paper is structured as follows: In the experimental system, the developed AGV platform hardware architecture is described. In fuzzy controller design, the stable fuzzy logic controller is presented. The next section describes the simulation and experimental results, and then the conclusions and some research directions.

THE EXPERIMENTAL SYSTEM

A. The Structure of the AGV platform and Additional Hardware, Figure 1.

B. Kinematic Modeling

Instantaneous posture errors (position and orientation errors) of vehicle are provided by the vehicular CCD camera in local coordinate as navigation information. The kinematics model in a local reference frame is shown in Figure 2, which is defined, considering a fixed reference frame coordinates (X_L, Y_L) situated on the center of mass and having the X_L axis along the vehicle's length, and (X, Y) is the global reference frame coordinates. As it is shown, position error ε_d is the perpendicular distance between the mass center O_L and the tangent to the desired path, and orientation error ε_θ is the angle between vehicle orientation and the tangent to the desired path. If the rotation of axis X_L to the guideline is anticlockwise, is plus, and otherwise is minus. V_L and V_R is linear velocity of left and right driving-steering wheel, respectively. The instantaneous longitudinal velocity V_A, and angular velocity ω, of the origin of AGV at its mass center are also show. Furthermore, D is defined as the distance between two driving wheels.

Vehicle with steered wheels independently raise a challenge because of the difficulty in satisfying the rigid body kinematic constraints for all wheels in a variety of paths. An approach for alleviating effects of wheel slippage is obtained by limiting the steering angles to small values, such that the two driving-steering wheels can be assumed to have the same steering angle. When the instantaneous center I_C of path rotates an angle, the relationship among linear velocities and angular velocity according to rigid body translation principle is defined as:

$$\begin{cases} V_A = \dfrac{V_L + V_R}{2} \\ \omega = \dfrac{V_L - V_R}{D} \end{cases} \tag{1}$$

Controlling variable of speed difference ΔV is generated to make V_L and V_R different when the path errors occur, so they become:

$$\begin{cases} V_L = V_A + \Delta V \\ V_R = V_A - \Delta V \end{cases} \tag{2}$$

As known, a differential-drive vehicle modeled by (1-2) can move on paths of arbitrary curvature C, as

$$\varphi = \frac{2}{D} \frac{V_R - V_L}{V_R + V_L} \tag{3}$$

From this equation, we can get following information: the curvature φ is infinite when $V_R = -V_L$, that means the vehicle would turn on the spot. While $V_R = V_L$, the curvature φ is zero, that means the vehicle would go forward straightly. Here we assume V_R and V_L be bounded by the given value V_b, then φ can be presented as follow:

$$\varphi \in \left[-\frac{2}{D}, \frac{2}{D} \right] \quad \text{where } V_R,\ V_L \in [0,\ V_b] \tag{4}$$

At any time, the location and position of AGV in the global reference frame coordinates can be uniquely determined by variables X_t, Y_t and β. Therefore, when the derivatives of X_t, Y_t and β are selected as state variables, we can get following equation from Fig. 2.

$$\begin{bmatrix} X_t' \\ Y_t' \\ \beta' \end{bmatrix} = \begin{bmatrix} \cos\beta & 0 \\ \sin\beta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_A \\ \omega \end{bmatrix} = \begin{bmatrix} \dfrac{\cos\beta}{2} & \dfrac{\cos\beta}{2} \\ \dfrac{\sin\beta}{2} & \dfrac{\sin\beta}{2} \\ -\dfrac{1}{D} & \dfrac{1}{D} \end{bmatrix} \begin{bmatrix} V_L \\ V_R \end{bmatrix} \tag{5}$$

When status s is turned to status s+1 in interval T_k, the angle rotated of AGV around the center I_C is β. Orientation error and position error at status s+1 is

$$\begin{cases} \varepsilon_\theta(s+1) = \varepsilon_\theta(s) + \dfrac{2\Delta V(s) T_k}{D} \\ \varepsilon_d(s+1) = \varepsilon_d(s) - V_A T_k \sin \dfrac{\varepsilon_\theta(s) + \varepsilon_\theta(s+1)}{2} \end{cases} \tag{6}$$

When ε_θ is small, the position error at status s+1 can be simplified by relevant processing. Hence, the kinematics model under the condition of small path errors is obtained:

$$\begin{cases} \varepsilon_\theta(s+1) = \varepsilon_\theta(s) + \dfrac{2\Delta V(s) T_k}{D} \\ \varepsilon_d(s+1) = \varepsilon_d(s) - V_A \varepsilon_\theta(s) T_k - V_A \dfrac{T_k^2}{D} \Delta V(s) \end{cases} \tag{7}$$

C. Fuzzy Control

Fuzzy logic handles approximate information in a systematic way. It can be thought of as an extension of Boolean logic which allows for the processing of partial truth values between completely true and completely false. Fuzzy logic is ideal for modeling complex systems where only an inexact model exists. Fuzzy membership functions quantify the extent to which an attribute is imprecise. Fuzzy logic involves three steps: fuzzification, fuzzy inference and defuzzification (Mike and Simon, 2006).

1. Fuzzification: In the process of fuzzification, no information is lost. It is simply changed to a different form, from a real value to degree of membership. In fuzzy logic systems, the ability to represent a large number of crisp logic values by using a small number of fuzzy values is very powerful. The membership functions defined on the input variables are applied to determine the degree of truth of the actual values. Each input value needs to be converted into a form in which the rules can operate on.
2. Fuzzy Inference: All inputs received by the system are evaluated using IF THEN rules that determine their truth values. Partial matching of the input data is used to interpolate an answer. All fuzzy results obtained by the inference are combined into a single conclusion. Many different techniques exist to find the most appropriate conclusion. For our control system, the MAX-MIN method of selection was used, in which the maximum fuzzy value of the inference conclusions was used as the final conclusion.
3. Defuzzification: After the rules have been processed, the recommended action needs to be converted from an internal representation to a precise output value. This step is necessary because the controllers of physical systems require discrete signals. Many methods of defuzzification exist. We use the center of gravity method, which is given as:

$$U = \frac{\int_{\min}^{\max} u\mu(u)du}{\int_{\min}^{\max} \mu(u)du} \tag{6}$$

where U is the crisp output value, u is the crisp representative value, and $\mu(u)$ is the grade of membership at u.

FUZZY CONTROLLER DESIGN

The purpose of this controller is to control the steering angle of driving wheels when the posture errors change, the structure of fuzzy controller is shown in Figure 3.

One of the most important issues in fuzzy controller

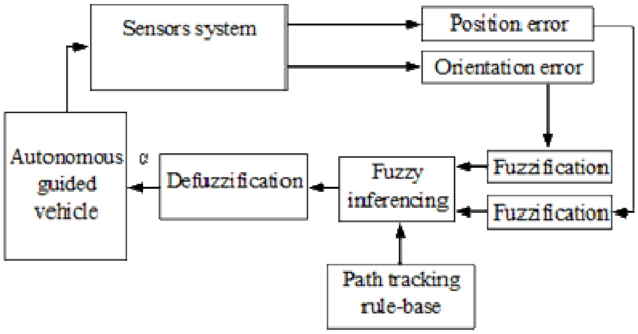
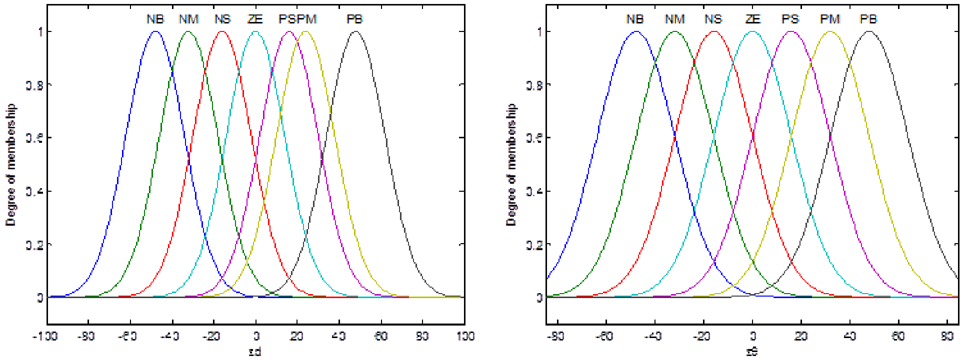
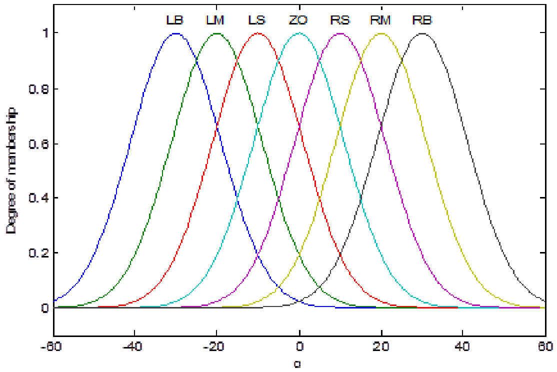


Figure 3. Proposed control structure



(a) Position error ε_d member function (b) Orientation error ε_θ member function



(c) Steering angle α member function

Figure 4. Member functions

design is the choice of the inputs and outputs of the system. As is shown in Figure 3, the inputs to the proposed fuzzy controller are position error ε_d and orientation error ε_θ, the output is steering angle α. We use singleton fuzzification and Mamdani inference strategy. The crisp control output is obtained through center-of-gravity (COG) defuzzification, and this method returns the center of area under the curve of the output membership. The kind of shapes used for the membership functions is a Gaussian, and these are simpler and easier to optimize and tune. As is shown in Figure 4, whether the position error ε_d is negative or positive depending on whether it is on the left side or on the right side of the tangent to the desired path and the range of it is between –1m and 1m. Similarly, whether the orientation error ε_θ is negative or positive depending on the rotation of axis X_L to the desired path is anticlockwise or otherwise, and the range of it is between –80°and 80°. It is to be noted that the fuzzy sets for the input variables and output variable are seven in Figure 4. Therefore, the fuzzy language values of two input variables include negative big (NB), negative medium(NM), negative small(NS), zero(ZO), positive small(PS), positive medium(PM) and positive big(PB). As output of fuzzy control, the steering angle α of AGV has fuzzy language values of left big (LB), left medium (LM), left small (LS),

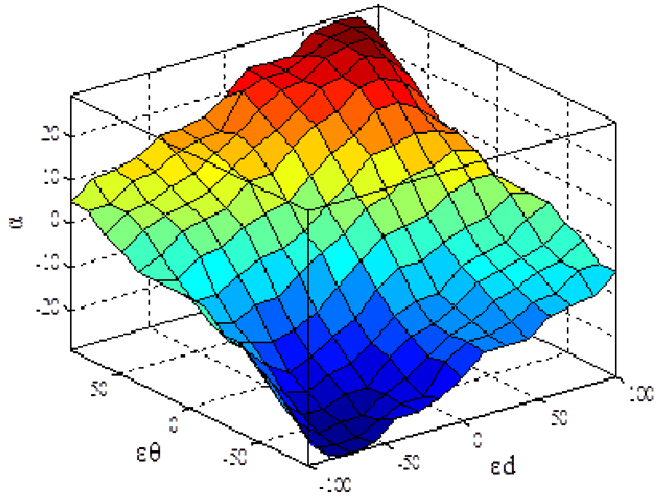


Figure 5. Fuzzy control surface for AGV

Table 1. Rule base in simulation and experiment

α		ε_d						
		NB	NM	NS	ZO	PS	PM	PB
ε_θ	NB	LB	LB	LM	LM	LM	LS	LS
	NM	LB	LM	LM	LS	LS	LS	ZO
	NS	LM	LS	LS	LS	LS	ZO	ZO
	ZO	LS	LS	LS	ZO	RS	RS	RS
	PS	ZO	ZO	RS	RS	RS	RM	RM
	PM	ZO	RS	RS	RS	RM	RM	RB
	PB	RS	RS	RM	RM	RM	RB	RB

zero(ZO), right small(RS), right medium(RM) and right big(RB), and the range of it is from –60° to 60°. Figure 4 shows the two input membership functions and the one output membership function.

The input and output of the fuzzy mechanism are real numbers and therefore the fuzzy model is always applicable whenever mathematical models are applied. Thus a fuzzy model can be formally defined by mathematical functions. It is generally a nonlinear model and has a good robustness to the noise. For the model properties, it is possible to refer to the control fuzzy surface (see Figure 5) of the autonomous guided vehicle.

Using human driving experience, by defining a set of membership functions for the position error ε_d and the orientation error ε_θ, one gets a total of 49 rules (7x7) with the following fuzzy implication

IF ε_d is J and ε_θ is K Then α is P

where

$J = K =$ {NS, NM, NB, ZO, PS, PM, PB}

$P =$ {LS, LM, LB, ZO, PS, PM, PB}

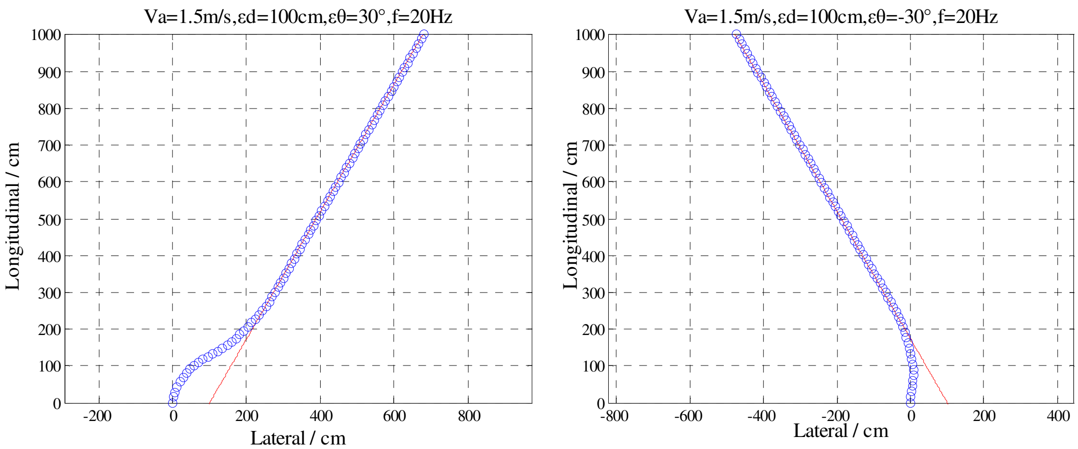
The entire "rule base" describing the fuzzy controller is presented in Table1. In this research, An IPC-68 II VDNF 750-MHz Pentium III processor is implemented as the motion controller. Due to its high process speed, it can afford to process complex algorithms, such as the defuzzification procedure in the fuzzy logic and there not be a lot of time to be wasted.

Closed-loop kinematic control for AGV proposed in this paper requires posture estimate relative to the world. Dead reckoning refers to estimate of the posture by using wheel rotation information alone. But the dead-reckoned estimate will be inaccurate over long distances travelled due to imprecisely known initial conditions, errors in the kinematic model, or disturbance during a physical motion, such as wheel slippage. To correct the posture estimate, visual, ultrasonic, and global positioning sensors are frequently adopted to provide the environmental information. In the combined estimation, considering the slow response of an environmental sensor such as machine vision, the dead reckoning may be allowed to dominate the posture estimate, and the environmental sensor, whenever its output is available, provides information to correct the estimate.

SIMULATION AND EXPERIMENTAL RESULTS

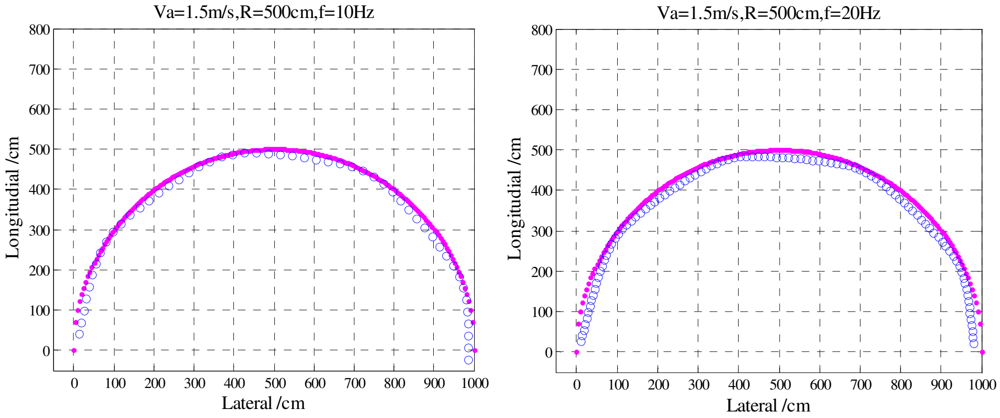
Simulation Results

Simulation of intelligent vehicle path tracking using the



(a) (b)

Figure 6. Simulation results of path tracking for line



(a) (b)

Figure 7. Simulation results of path tracking for curve

fuzzy control method is carried out to evaluate the effectiveness of the proposed schemes. Figure 6 to Figure 7 show the simulation results of the intelligent vehicle tracking line path and curve path by the fuzzy control method respectively.

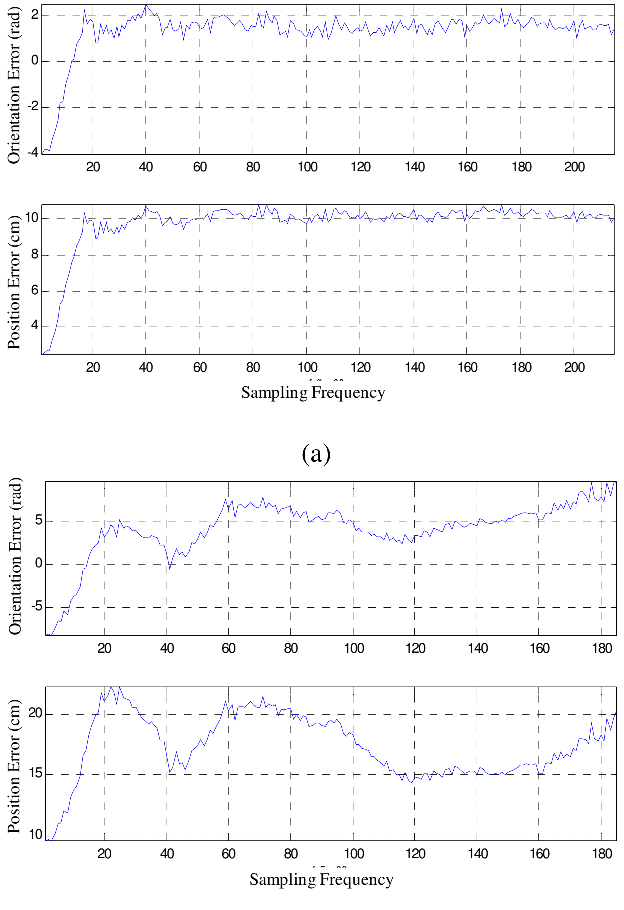
The desired line trajectory is defined by (ε_d = 100cm, ε_θ = 30°) and (ε_d = 100cm, ε_θ =–30°) in Figure 6 respectively. They are the approximate trajectory lines when initial vehicle speed V_a = 1.5m/s and sampling frequency f = 20Hz. The radius of desired arc trajectory is 500cm and different sampling frequencies are also employed to observe the tracking performance in Figure 7.

It is to be noted that the intelligent vehicle with higher sampling frequency can get better tracking performance with the less tracking errors. However, as seen from Figure 6 to Figure 7, the intelligent vehicle has less tracking errors when it tracks line paths compared with the curve path caused by the arbitrary situations in curve trajectory. We see that this fuzzy controller successfully drives the vehicle to the desired trajectory starting from an arbitrary initial state.

Experimental Results

This section shows the experimental results obtained with the proposed kinematic controller, the controller was implemented in a practical experiment platform as shown in Figure 9.

For the first experiment, a straight reference trajectory is used, starting at the initial position error ε_d = 50cm and orientation error ε_θ =30°. In the second test, the reference trajectory is arc with radius of 500cm. As shown in Figure 8 (a) and (b), the vehicle follows the path reference with an acceptable performance although it shows an appreciable error in some parts of the path. The line tracking errors are smaller than curve tracking errors. This is due to the fact that the curve path is complicated and



(a)

(b)

Figure 8. (a) Experiment results of path tracking for line. (b) Experiment results of path tracking for curve.

Figure 9. V-AGV experimental platform

the navigation parameters obtained by the image processing change swiftly, and the actuator (i.e. servos motor) of the system is difficult to respond the changes in real time. Furthermore, the same problems are applicable to the high-speed tracking. Overall, from the experimental results, it can be seen that we are able to get good performance for path tracking of vehicles within its physical limitations.

CONCLUSION

The advantage of fuzzy controller is that it can add new control rules to improve system performance and the system cannot overall paralyzed due to the failure of a few rules. In this paper, the kinematic model was proposed to analyze stability of motion of the controlled vehicle at first. Furthermore, through the combination of orientation error and position error information, a fuzzy controller consists of 2-to-1 mapping was established. In addition, by referencing driving experience of excellent drivers, the quantification and segmentation were applied to control rules. In our research, a CCD camera based vision sensor performs periodic image acquisition and path planning to derive the reference path. In simulations and experiments, the stability and performance of the controller have been verified. However, some stochastic algorithms, like Lyapunov theory, differential evolution, harmony search (Das-Sharma et al., 2010)., etc., can be potentially employed to design a coupled fuzzy controller. The authors wish to research the stability of the coupled fuzzy controller using these optimization algorithms for vision-based navigation in the future.

REFERENCES

Amidi O (1990). Integer Mobile Robot Control. Carnegie Mello University Robotics Institute Technical Report. 17: 27-31.

Chen W, Sun H, Li B (2006). Tracking control of automatic guided vehicle based on lane marker navigation. Chinese J. Mech. Engr. 42: 164-170.

Chu J, Wang R, Guo K, Gu B, Ma L (2002). Study for control system of a two-wheel difference speed steering AGV based on machine vision. Machinery and Electronics. 5: 51-55.

Das-Sharma K, Chatterjee A, Rakshit A (2010). Design of a hybrid stable adaptive fuzzy controller employing Lyapunov theory and harmony search algorithm. IEEE Transaction Control System Technology. 18: 1440–1447.

El-Hajjaji A, Bentalba S (2003). Fuzzy path tracking control for automatic steering of vehicles. Robotics and Autonomous Systems. 43: 203-213.

Hunt KJ, Kalkkuhl J, Fritz H, Johansen TA, Gottsche TH (1998). Experimental comparison of nonlinear control strategies for vehicle speed control. Proc. IEEE Int. Conf. Contr. Applicat., Italy. 9: 1006–1010.

Kamga A, Rachid A (1996). Speed, steering angle and path tracking controls for a tricycle robot. Proc. IEEE Int. Symp. Comput.-Aided Contr.Syst. Design, Dearborn, MI. 9: 56–61.

Kanayama I, Yuta S (1988). Vehicle Path Specification by a Sequence of Straight Lines. IEEE Journal of Robotic and Automation. 4: 265-276.

Kodagoda KRS, Wijesoma WS, Teoh EK. (2002). Fuzzy Speed and Steering Control of an AGV. IEEE Transactions on Control Systems Technology. 10: 112-120.

Mike D, Simon XY (2006). Two-Stage Fuzzy Logic-Based Controller for Mobile Robot Navigation. Proceedings of the IEEE International Conference on Mechatronics and Automation, Luoyang, China, 5: 745-750.

Romuald A, Roland C (2002). Accurate road following and reconstruction by computer vision. IEEE Transactions on Intelligent Transportation Systems. 3: 261-270.

Yang M (2006). Overview and prospects of the study on driverless vehicles. Journal of Harbin Institute of Technology. 38: 1259-1262.

Zadeh LA (1965). Fuzzy sets. Journal of Information and Control. 8: 338-353.

Zalila Z, Bonnay F, Coffin F (1998). Lateral guidance of an autonomous vehicle by a fuzzy logic controller. IEEE Int. Conf. Syst, Man, Cybern. 2: 1996–2001.