Position and Attitude Alternate of Path Tracking Heading Control

Baocheng Tan, Feng Lv

School of Electronic Information Engineering, Xi'an Technological University, Xi'an 710032, China
Tel.: 15829901685
E-mail: 1595793678@qq.com

Abstract: The path tracking control algorithm is one of the key problems in the control system design of autonomous vehicle. In this paper, we have conducted dynamic modeling for autonomous vehicle, the relationship between course deviation and yaw rate and centroid deflection angle. From the angle of the dynamics and geometrical, this paper have described the path tracking problem, analyzed the emergence of the eight autonomous vehicles pose binding - position and attitude alternate control methods to identify the relationship between posture and the controlling variables, and design a controller, the experimental results verify the feasibility and effectiveness of this control method. *Copyright © 2014 IFSA Publishing, S. L.*

1. Introduction

With the combination of Modern high-tech and automotive technology, unmanned vehicle occupies an important role in the intelligent transportation in the future, which using automotive radar, GPS, inertial navigation and the central control system to guide the vehicle to drive safely. Central control system which based on detected traffic information sent forward all kinds of instruction to the actuator, such as acceleration, steering, avoidance, braking and so on. And then complete the corresponding operations by the actuator.

The main purpose of the unmanned vehicles heading path tracking control is to track the given path, -making the vehicles running along the given path driving safely. At the same time, its performance directly influences the execution of the unmanned vehicle intelligent behavior ability. Since the path tracking control system is impacted by strong nonlinear of the vehicle itself and the changes

of kinetic parameters (Speed, yawing angular velocity, lateral wind and road adhesion coefficient and vehicle quality, etc.), therefore, how to design an accurate heading control system is one of the heated issues of the unmanned vehicle. The literature [1] designed a preview and feedback controller, which is using the current path information as feedback and the future path information as a preview. The preview distance and unmanned vehicle speed adjusted automatically according to the preview of the bending path degree. Although this method can get a higher accuracy of the path tracking effect in theory, it must be accurate in front of the road curvature information. So it is more difficult to achieve in the unstructured road; the literature [2] is proposed the tracking control system based on the path of the yawing angular velocity; the literature [3] studied the preview steering control problems of the unmanned vehicle path tracing by nonlinear h-infinity state feedback; literature [4] presented road tracking system on the base of the kinematics

relationship between vehicle and road. These methods are intuitive and have clear physical meaning, but the parameters of the controller must be adjusted by real vehicle experiment. As the change of vehicle speed is bigger, how to adjust the optimal controller parameters is difficult to measure.

Firstly this article establish the dynamic model of unmanned vehicle, and then analysis the influencing factors of vehicles heading error; as the vehicle driving state a reference, and using the difference between the given heading and the current heading value as deviation, Combined with the posture alternating control method to calculate the amount of steering control, which is in order to make current heading precision tracking for a given heading.

2. Dynamic Model

Mathematical model of unmanned vehicles designs on the basis of the controller. It is vital to find out the relationship between unmanned vehicle system state parameters and the control parameters which provides a theoretical basis, aimed at designing an effective control law and realizing accurate path tracking of an unmanned vehicle. The unmanned vehicle model based on the kinematics builds the mathematical relationship between the position posture and velocity of movement, from the displacement, velocity, angular velocity and other physical quantities' point of view.

With two degrees of freedom (lateral movement along the Y axis and yaw movement along the Z axis) monorail vehicle model, the whole body can be viewed as a whole and the vehicle longitudinal velocity along the X axis can be regarded as constant. What's more we assume the other conditions except tire lateral force's calculation [5]. Through the above assumptions, the vehicle model is shown in Fig. 1.
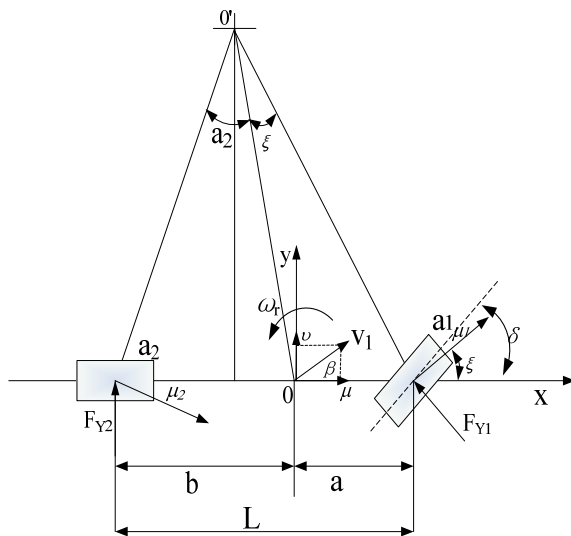

Fig. 1. The Vehicle Model.

δ is the tire slip angle; F_{Y1} and F_{Y2} are the force of the wheels respectively' a, b is the distance from the vehicle center of gravity to the front and rear axle; L is the vehicle wheelbase.

When analyzing movement state of the system, we put the center of mass as the origin of the vehicle model. The vehicle velocity, acceleration and force have to discompose along X, Y, Z axis of the model coordinate system [7], so we get the dynamic equations of the vehicle:

$$m(\dot{v} + u\omega_\gamma) = (k_1 + k_2)\beta + \frac{1}{\mu}(ak_1 - bk_2)\omega_\gamma - k_1\delta \tag{1}$$

$$I_z\dot{\omega}_r = (ak_1 - bk_2)\beta + \frac{1}{\mu}(a^2k_1 + b^2k2)\omega_\gamma - ak_1\delta \tag{2}$$

By Formula 1, 2, and the physical meaning of the yaw angular velocity, the dynamic model expression based on heading deviation can be obtained [8]:

$$\dot{\beta} = \frac{bk_2 - ak_1}{mu^2}r + \frac{k_1}{mu}\delta - \frac{k_1 + k_2}{mu}\beta - r \tag{3}$$

$$\dot{r} = \frac{bk_2 - ak_1}{\omega_r}\beta - \frac{a^2k_1 + b^2k_2}{\omega_r u}r + \frac{ak_1}{\omega_r}\delta \tag{4}$$

$$\dot{lp} = r \tag{5}$$

Among them: m is quality of the vehicle; k_1, k_2 is the cornering stiffness of the front and rear axle respectively; u is the vehicle longitudinal speed; ω_r is the movement of inertia of Z axis; δ is the front-wheel declination; r is the yaw angular velocity; β is the deflection angle of the center of mass; lp is the vehicle heading.

3. Path Tracking and the Control

3.1. Description of Path Tracing Problem

The geometric description of the unmanned vehicle expecting tracking path is shown in Fig. 2 [9]. In the figure, the XOY is reference coordinate system of the earth; xoy is the fixed coordinate system of the vehicle body; hv is yaw angle of the unmanned vehicle; v, vx, vy is respectively the unmanned vehicle velocity, longitudinal velocity and lateral velocity; vd is the desiring velocity of the unmanned vehicle, which is the tangential velocity of the unmanned vehicle along the expected path; β is the deflection angle of the center of mass; ej is the angle of ox and the tangent of expecting path, which is yaw angular deviation [10, 11].
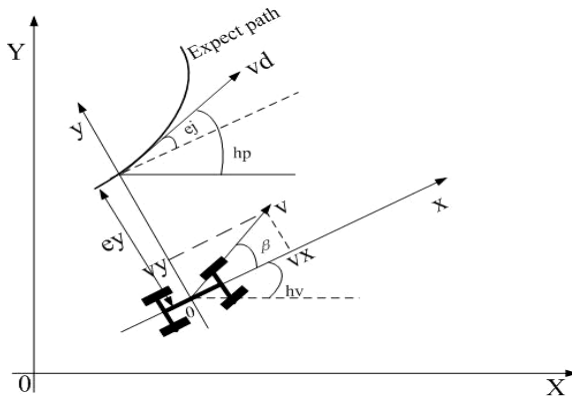
Fig. 2. Route of unmanned vehicle tracking diagram.

According to Fig. 2, the mathematical model of path tracking is obtained:

$$\dot{ey} = vd \, \sin(hv) - vy \tag{6}$$

$$\dot{ehv} = vd * qp - \omega \tag{7}$$

In the Formula 7 ω is yawing angular velocity of the unmanned vehicle; qp is the curvature of point p of the expecting the path.

3.2. The Structure of Path Tracking Heading Control System

The unmanned vehicle path tracking heading system is composed of the servo drives, performing motors, feedback drives, connectors and other components [13]. The actuator controls the heading through engagement of the gear of a 400 W AC servo motor and the gear of direction axis. Function of the system based on a given path heading, control front wheel turning makes the vehicle driving along the given path heading. In the working process of system, the host computer as main control unit receives the current heading of vehicle from GPS. Comparing the current heading with a given heading, the front wheel corner controlled variable is generated and this control variable is compared with the actual front wheel corner signal which is feedback by corner sensor.

The result of the comparison will provide drive motor corner control value through a certain algorithm so as to realize the change of the vehicle heading. The structure path tracking heading control system is shown in Fig. 3.
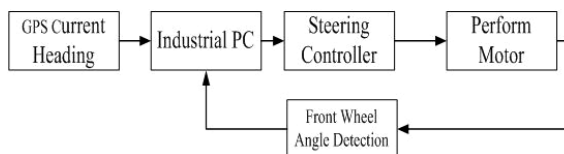

Fig. 3. The structure of path tracking heading control system.

3.3. Path Tracking and Vehicle Posture of Judgment

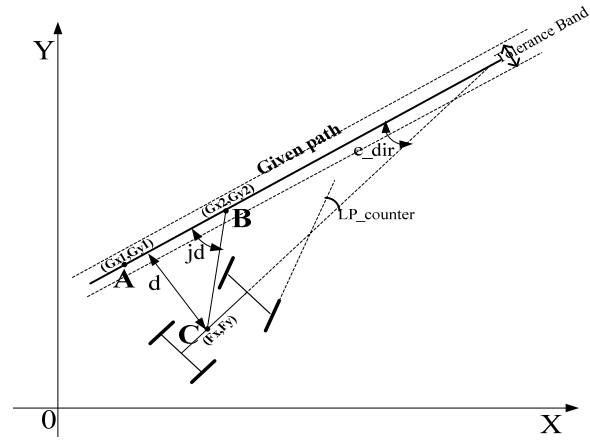Fig. 4 shows reference coordinate system of the earth and the path tracking geometric figure.

Fig. 4. Path tracking geometric figure.

In Fig. 4: A and B are the coordinates of any two points in the a given path; the point C is the center of mass; jd represents the angle between two straight lines; d is the distance between the vehicle and a given path; LP_counter represents the front wheel turning; e_dir represents the difference between the current heading and the given heading.

$$k1 = \frac{Gx1 - Gx2}{-(Gy2 - Gy1)} \tag{8}$$

$$c = -(Gx1 - Gx2)Gy1 - (Gy2 - Gy1)Gx1 \tag{9}$$

$$d = \frac{|(Gy2 - Gy1)Fx1 + (Gx1 - Gx2)Fy1 + c|}{\sqrt{(Gy2 - Gy1)^2 + (Gx1 - Gx2)^2}} \tag{10}$$

$$k2 = \frac{Fy - Gy2}{Fx - Gx2} \tag{11}$$

$$YC = (fx - Gx2)^2 + (fy - Gy2)^2 \tag{12}$$

$$e\_dir = Dh - Gh \tag{13}$$

$$jd = \frac{(Gx2\text{-}Fx)(Gx2\text{-}Gx1) + (Gy2\text{-}Fy)(Gy2\text{-}Gy1)}{\sqrt{(Gx2\text{-}Fx)^2 + (Gx1\text{-}Gx2)^2} * \sqrt{(Fx\text{-}Gx2)^2 + (Fy\text{-}Gy2)^2}} \tag{14}$$

In Formula (13), gps_hx represents the current heading which is received by GPS. buf (2, 1) represents the given heading.

According to Fig. 2 and each equation can be determined the following judgments on the unmanned vehicle position posture:

According to d can judge the distance between vehicle and the given path;

If jd > 0 and the current slope (k2) is greater than the given slope (k1), we can determine the vehicle path is located below the given path; on the contrary, above the given path.

When the vehicle is below the given path and if e_dir > 0, we can determine vehicle point close to path; on the contrary if e_dir < 0, then we can decide the vehicle away from the path;

When the vehicle above a given path and if e_dir > 0, we can determine vehicle away from path; on the contrary if e_dir < 0, then you can decide the vehicle point close to the path;

If the tolerance (YC) is within the tolerance band or jd < 0, then it means the unmanned vehicles arrives as the given point. Taking the next point, we continue to determine position posture.

4. Design of Heading Fuzzy Controller

In the process of the unmanned vehicle tracking the path, regardless of the path given is a straight line or curve, we can deal with it as many differential line segments. Under each of the line segment, the unmanned vehicle will appear in eight kinds of position as shown in Fig. 5.
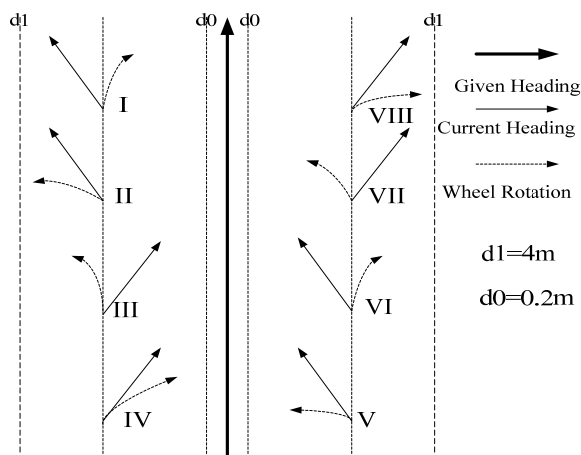

Fig. 5. The posture between the unmanned vehicle and the given path.

The position posture alternate control method [12, 15]: when there is a large position error, it is main to reduce the position error in order to track fast by controlling the position; when there is a small position error, it is main to improve the accuracy, furthermore to improve the tracking precision by position posture controlling. So in the condition of different distance and heading deviation value, the controller output corner is also different. Combined with the parameters of the unmanned vehicle, the fuzzy control rules we have established are as follows:

1) If d < do that means unmanned vehicles is within the tolerance band, then the vehicle can keep the turning controlling quality outputted by the controller (ELP_counter) as constant.

2) If do < d < d1, depending on status, the control of the output is different:

A) When the vehicle is in state (I), at this time the vehicle is located above the given path (jd > 0, k2 < k1), the heading difference (e_dir < 0), it means that vehicle corner (LP_counter < 0). If LP_counter > jd, in order to quickly close to the given path, we adjust fine the vehicle corner to turn left and ELP_counter=0.6*(e_dir)*56000/45; if LP_counter < jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.6*(-e_dir)*56000/45;

B) When the vehicle is in state (II), at this time the vehicle is located above the given path (jd > 0, k2 < k1), the heading difference (e_dir < 0), it means that vehicle corner (LP_counter > 0), at this time in order to quickly adjust the vehicle position distance, we turn right fast, ELP_counter = 1.5*(e_dir)*56000/45; when LP_counter < 0, if LP_counter < jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.6*(e_dir)*56000/45; if LP_counter > jd, we adjust fine the vehicle corner to turn left and ELP_counter = 0.6*(-e_dir)*56000/45;

C) When the vehicle is in state (III), at this time the vehicle is located above the given path (jd > 0, k2 < k1), the heading difference (e_dir > 0), the vehicle corner (LP_counter > 0), at this time in order to quickly adjust vehicle distance, but in order to ensure the accuracy of heading control, we turn right to fast, ELP_counter=1.5*(-e_dir)*56000/45; when LP_counter < 0, if LP_counter > jd, we adjust fine the vehicle corner to turn left and ELP_counter=0.3*(e_dir)*56000/45; if LP_counter < jd, we adjust fine the vehicle corner to turn right and ELP_counter= 0.3*(-e_dir)*56000/45;

D) When the vehicle is in state (IV), at this time the vehicle is located above a given path (jd > 0, k2 < k1), the heading difference (e_dir>0), the vehicle corner (LP_counter > 0), if LP_counter > jd, we adjust fine the vehicle corner to turn left and ELP_counter=0.3*(e_dir)*56000/45; if LP_counter < jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.3*(-e_dir)*56000/45;

E) When the vehicle is in state (V), at this time the vehicle is located below the given path (jd > 0, k2 > k1), the heading difference (e_dir < 0), the vehicle corner (LP_counter > 0), if LP_counter > jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.3*(e_dir)*56000/45; if LP_counter < jd, we adjust fine the vehicle corner to turn left and ELP_counter=0.3*(-e_dir)*56000/45;

F) When the vehicle is in state (VI), at this time the vehicle is located below the given path (jd > 0, k2 > k1), heading difference (e_dir < 0), (LP_counter < 0), at this time in order to quickly adjust vehicle distance, we turn left fast, ELP_counter=1.5*(-e_dir)*56000/45; when LP_counter > 0, if LP_counter < jd, we adjust fine the vehicle corner to turn

left and ELP_counter=0.6*(-e_dir)*56000/45; if LP_counter > jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.6*(e_dir)*56000/45;

G) When the vehicle is in state (VII), at this time the vehicle is located below the given path (jd > 0, k2 > k1), the heading difference (e_dir > 0), the vehicle corner (LP_counter > 0), if LP_counter > jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.3*(-e_dir)*56000/45; if LP_counter < jd, we adjust fine the vehicle corner to turn left and ELP_counter=0.3*(e_dir)*56000/45;

H) When the vehicle is in state (VIII), at this time the vehicle is located below a given path (jd > 0, k2 > k1), the heading difference (e_dir > 0), vehicle corner (LP_counter < 0), we turn left fast, ELP_counter=1.5*(e_dir)*56000/45; when LP_counter > 0, if LP_counter < jd, we adjust fine the vehicle corner to turn left and ELP_counter=0.6*(e_dir)*56000/45; if LP_counter > jd, we adjust fine the vehicle corner to turn right and ELP_counter=0.6*(-e_dir)*56000/45;

3) When d > d1, at this time the vehicle deviates too far away from the given path, and it is beyond the scope of control. In order to safety period, choose to stop.

5. Experimental Verification

Our experiment provides the information of the given path tracking path is including the x coordinates, y coordinates, the given heading. Here we give some parts of the program.

```
Private Sub MSComm1_OnComm()
Select Case MSComm1.CommEvent
    Case comEvReceive
    Call Read_GPS
End Select
End Sub
Sub COMPH()
Dim deltx1, delty1, deltx2, delty2, jd As Variant
Dim jd_a, jd_b As Double
If (jd_a = 0) Or (jd < 0) Then
 s = s + 1
 F_dir = False
Else
    k2 = delty2 / deltx2
End If
If F_dir = True Then
If d > 4 Then
   d_date = 3
ElseIf d <= 4 And d > 1 Then
   d_date = 2
ElseIf d <= 1 Then
   d_date = 1
End If
 If 0 < jd Then
   If Fangk > Geik0 Then
      F_symbol = 0
   Else
```

```
      F_symbol = 1
   End If
  End If
AdvAO1.DataAnalog=speed_i - speed_k * d_date
xz_i = 0
Select Case d_date
Case 2
If F_symbol = 0
Then
      out_pulse = e_dir*560000/45-LP_counter
    End If
        e_dir1 = e_dir
        Call RETURE
     End If
   End If
   If (F_symbol=0) And (LP_counter > 0) And
(e_dir < -5)
Then
        out_pulse = -LP_counter
        Call RETURE
        End If
    Else
        out_pulse = -limit_pulse4 - LP_counter
        e_dir1 = e_dir
        Call RETURE
        xz_i = 4
     End If
   End If
   If ((e_dir - e_dir1) < 1.5) Then
     timer_counter = timer_counter + 1
   Else
      timer_counter = 0
   End If
  If (timer_counter >= 7)
Then
     If (F_symbol = 1) And (e_dir < 0) Then
     out_pulse = 1.1 * e_dir * 560000 / 45
   If out_pulse + LP_counter < -limit_pulse4
Then
     out_pulse = -limit_pulse4 - LP_counter
        End If
        e_dir1 = e_dir
        Call RETURE
        xz_i = 5
        timer_counter = 0
    End If
   End If
     If (F_symbol = 1) And (LP_counter < 0)
And (e_dir > 5)
Then
        out_pulse = -LP_counter
        Call RETURE
        xz_i = 6
     End If
   End If
```

In Table 1 has given a set of experimental path information. Heading 180° pointing south, it can be seen from Table 1 that vehicle toward the south has driven about 90.505 meters, the experimental results (vehicle velocity is 10 km/h, the tolerance zone is 0.5 m) is shown in Fig. 6.

It can be seen from Table 2 that vehicle toward the south and east has driven about 121 meters, the experimental results (vehicle velocity is 10 km/h, the tolerance zone is 0.5 m) is shown in Fig. 7.

It can be seen from results of the experiment, position posture alternate fuzzy control makes the control of unmanned vehicle heading's robustness and stability greatly increased.

Table 1. Path table.

No.	1	2	3	4
X Coordinate	3793747.946	3793733.45	3793683.794	3793657.441
Y Coordinate	591519.514	591519.586	591519.869	591517.011
Heading	179.32	179.84	179.37	179.52
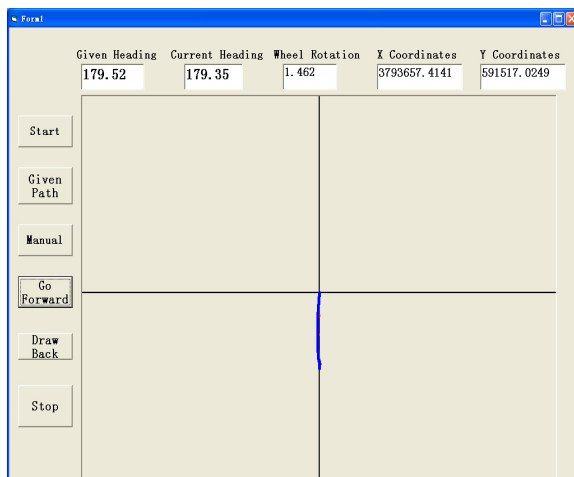
Fig. 6. Display of experimental results. (The blue line shows the real time vehicle trajectory).
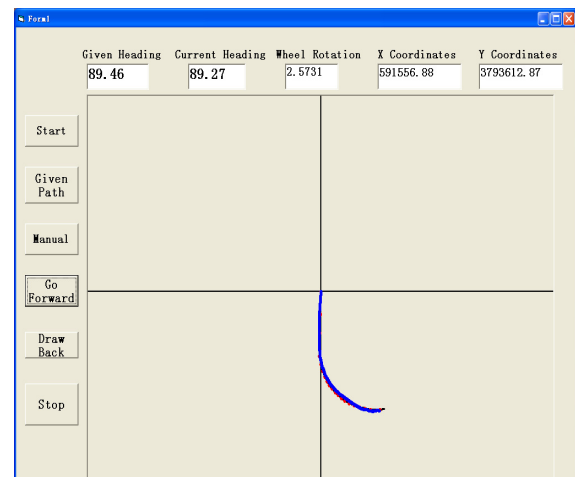
Fig. 7. Display of experimental results. (The blue line shows the real time vehicle trajectory).

Table 2. Path table.

No.	1	2	3	4	5	6
X Coordinate	3793747.946	3793733.364	3793698.157	3793655.496	3793623.438	3793612.843
Y Coordinate	591519.589	591519.476	591522.452	591527.621	591541.658	591556.711
Heading	179.68	179.35	158.62	124.45	96.37	89.46

6. Conclusions

Using position posture alternate fuzzy control algorithm makes the unmanned vehicle in a wide speed range have good performance of path tracing. The experimental results show that this method has good control effect on unstructured road and has strong robustness. Because the unmanned vehicles itself has a strong nonlinear and the external environment is uncertainties, if we use adaptive fuzzy PID control, by the means of heading error and heading error changing rate [14] as input, adjusting the parameters of the PID and adding some constraints in it, to further improve the control precision of the vehicle heading.

Acknowledgements

References

[1]. Wuguo Chen, Jin Li, Visual navigation path of intelligent car tracking aim control, *Journal of Mechanical Engineering*, 44, 10, 2008, pp. 277-282.

[2]. Junmin W., Steiber J., Surampudi B., Autonomous Ground Vehicle Control System for High-speed and Safe Operation, in *Proceedings of the American Control Conference*, 2008, pp. 218-223.

[3]. Thruns, Montemerlo M., Dahlkamp H., et al., Stanley: The Robot that Won the DARPA Grand Challenge, *Journal of Field Robotics*, 23, 9, 2006, pp. 661-692.

[4]. Li L., Feiyue W., Advanced Motion Control and Sensing for Intelligent Vehicle, *Springer,* Berlin, 2007.

[5]. Yuzhi Sheng, Theory of automobile, *Mechanical Industry Press,* Beijing, 2006.

[6]. Kook M., Stable adaptive fuzzy controller with time varying dead-zone, *Fuzzy Sets and Systems*, 121, 2001, pp. 161-168.

[7]. Madan M. Gupta, A Survey of Process Control Applications of Fuzzy Set Theory, in *Proceedings of the IEEE Conference on Decision and Control*, January 1979, pp. 1454-1461.

[8]. Prabhu Sameer M., An Overview of Neural Network and Fuzzy Logic Applications to Earthmoving Machine Systems Control, *SAE,* 1999, pp. 1801-1880.

[9]. Wuwei Chen, Qirui Wang, Based on the dynamic model of automatic Guided Vehicles intelligent navigation control research, *Journal of Agricultural Machinery*, 34, 4, 2003, pp. 90-93.

[10]. Xijun Zhao, Huiyan Chen, Research of intelligent vehicle routing track lateral control method, *Automotive Engineering*, 5, 2011, pp. 382-397.

[11]. Howard Li, Brandon C. Brown, Non-Time Based Motion Control for Multiple Intelligent Vehicles, in *Proceedings of the Canadian Conference on Electrical and Computer Engineering (CCECE '09)*, 2009, pp. 646-649.

[12]. Pomerleau D, RALPH: Rapidly Adapting Lateral Position Handler, in *Proceedings of the IEEE Symp. on Intelligent Vehicles*, 1995, pp. 506 - 511.

[13]. Yang Ming, Parent Michel, Cybernetic technologies for cars in Chinese cities. *Journal of Field Robotics* 2004, pp. 17-18.

[14]. Yannian-Rui, Wenjie Liu, Xiaoping Li, Zhiwei Zhang. Research on Vehicle Intelligent Braking Control Based on Neural Networks, *in Proceedings of the IEEE Neural Network Control, November, 1987, pp.178-196.*

[15]. S. Hahn, Automation of Driving Functions-Future Development, Benefits and Pitfalls, in *Proceedings of the IEEE Intelligent Vehicles Symposium,* 1996, pp. 309 - 312.

_____