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Human Simulating Control Algorithm on Vehicle Lateral Tracking

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Abstract—**In the paper, a new control algorithm called Human Simulating Control Algorithm (HS) is presented.. Unlike the traditional methods, the algorithm uses Sigmoid function to describe the steering operations of human drivers. Based on this function, HS algorithm is presented. In order to improve the adaptability to different environments, a parameter adaptive adjustment algorithm is presented. This algorithm can adjust the values of the key parameters real time. HS controller is used on a vehicle equipped with a computer vision system and a computer controlled steering actuator system, The results from the experiments show that the vehicle prototype with HS algorithm processed good tracking performance at different vehicle speed, even up to the speed of 172km/h.**

I. INTRODUCTION

The Neural Network algorithm and Fuzzy algorithm developed recently have been utilized to serve this purpose. The neural network algorithms can simulate the input and output in the vehicle control while vehicle model and the driver's operation rules aren't needed. There are three drawbacks for NN algorithms: The first is that the mount of the data is very large; the second the training must contain all kinds of the situations; the third is computation time of the network training is long and hardly be realized online. Fuzzy control algorithms need to build fuzzy rules in all kinds of the situations. But it is very difficult to build all the rules when a lot of factors influence the vehicle's lateral tracking[1][2][3].

A control algorithm called Human-Simulating steering control algorithm, HS for short, is presented in the paper[4]. There is no neural network algorithm or network framework in this algorithm and the computation is very simple. The relationship between the input and the output contains both linear and nonlinear. Human-Simulating steering controller is nonlinear, but it can be reduced into linearity under some situations.

II. THE DRIVER'S STEERING RULES

The visible trapezoidal area of the driver is as shown in the figure 1. The centerline of the field of the vision is the axis of the vehicle in the longitude. The reference line in the figure is the target line of the road. Variable α denotes the angle error, which is the angle between the axis of the vehicle in the longitude and the target line of the road. Variable le denotes he lateral displacement, which is the lateral displacement between the future position according to the current driving states and the target position at the looking-forward point. Axis of y is the heading direction of the vehicle. The driver's steering rules is as following:

A. *Only angle error (yaw) exists*

When the lateral displacement between position of the vehicle and target position at the lateral of the forward ahead is zero, there is only angle error. In this situation, the direction of the steering angle should be the same as that of the angle error. But the relation between the steering angle and the angle error is nonlinear, where is the ratio of the steering angle rate to the angle error rate. The smaller the absolute value of angle error, the higher the ratio is. As the

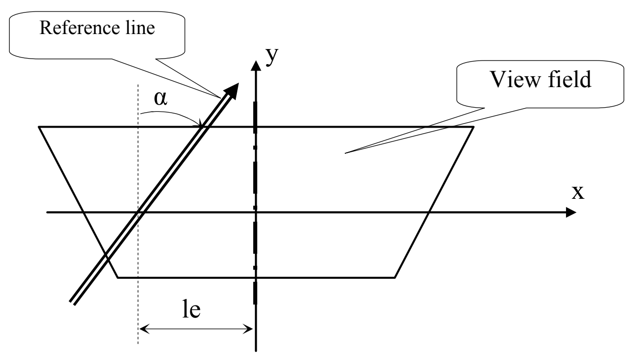

Fig.1 View field and reference line

increase of the absolute value of angle error, the ratio reduces. For example, as the angle error increase from 0 to 10 degree, the steering angle also increase from 0 to 10 degree, however when the angle error from 10 to 20 degree, the steering angle might from 10 to 14 degree at the utmost situation, the angle error 90, the steering angle must be the angle which are limited by the mechanic structure of the steering system.

B. *Only lateral displacement exists*

When angle error is zero, there is only lateral displacement. The direction of the steering angle is opposite to the direction of the lateral error. The mount of steering angle is related to the lateral error. The higher of the absolute value of the lateral error is , the higher of the steering angle is. But as the situation, which has been mentioned above, the relation between the steering angle and the lateral error is nonlinear, where $s_{lateral} = \frac{da}{dl_{lateral}}$ is the ratio of the steering angle rate to the lateral displacement rate. The lower the absolute value of lateral error, the higher the rate is. As the increase of the absolute value of lateral displacement, the ratio reduces. Finally, when the absolute value of the lateral error is higher than a fixed value, the rate reduces to 0, which means as the increase of the lateral displacement, the steering angle will not increase any longer.

C. Both angle error and lateral displacement exist

When both angle error and lateral displacement exist, steering angle is the overlap of the two situations that have been mentioned above.

From above, the steering rules are concluded as the following:

- When the absolute value of input parameter is low, the rate of the steering angle increase to the input parameters is very high. While in the opposite situation, the rate is low.
- The range of the lateral error and angle error is infinite, while the steering angle is finite which is limited by the mechanic structure of the steering system.

In this paper, a series of Sigmoid-based functions are used to describe these rules. They are yaw (angle error) control function, lateral control function and the combination of these two functions.

III. HS STEERING MODEL DESIGN

A. Sigmoid function

$$f(\alpha) = (1 - e^{-\lambda\cdot\alpha})/(1 + e^{-\lambda\cdot\alpha}) \text{ ....(1)}$$

The graphics of Sigmoid function is as shown in the figure 2. It is distinct that when the absolute value of the input is low or the input is close to the origin of the coordinates, the ratio of output rate to input rate is high. As the input increase, the rate reduces gradually into a fixed value.

The sigmoid function meets the steering rules Which are mentioned above.

Equation 2 is the differential function of the Equation 1:

$$f'(\alpha) = 2\cdot\lambda\cdot e^{-\lambda\cdot\alpha}/(1+e^{-\lambda\cdot\alpha})^2 \text{ ....(2)}$$

The graphics of the equation 2 is as shown in the Figure 3.

As shown in the figure 3, the function has the max value at the origin of the axis. As the absolute value of input increases , the value of the differential function decreases. As shown in the figure 3, the increase of the input doesn't affect the value of the function when the absolute value of the input is more than 20. These characteristics of the sigmoid function are accorded with the steering rules, which are mentioned above. Hence the design of steering controller is based on the sigmoid function.

B. Sensitive Factor

In the Sigmoid function, parameter λ is called as the sensitive rate, which is the ratio of output controller. The shape of differential function of sigmoid function with different values of the sensitive rate λ is shown in the Figure 4. It is obviously that the sensitive rate λ determines the changing rate of the output to the changing of the input. In the real control, the sensitive rate can be adjusted according to the vehicle speed.

C. Human-Simulating Control Model

Human-Simulating Control Model contains three parts: angle error control model, lateral control model, and the combination of these two kinds of models.

1) Angle error Control Model

$$\lambda_\alpha(\alpha) = k_\lambda \cdot \lambda_c \cdot e^{-\lambda_c\cdot\alpha} /(1 + e^{-\lambda_c\cdot\alpha})^2 + k_c \text{ ....(3)}$$

$$f_\alpha(\alpha) = k_\alpha \cdot (1 - e^{-\lambda_\alpha(\alpha)\cdot\alpha})/(1 + e^{-\lambda_\alpha(\beta)\cdot\alpha}) \text{ ......(4)}$$

In the equation 3, which is the differential function of the sigmoid function, describes the ratio of steering angle rate to angle error rate k_λ denotes sensitive coefficient, λ_c

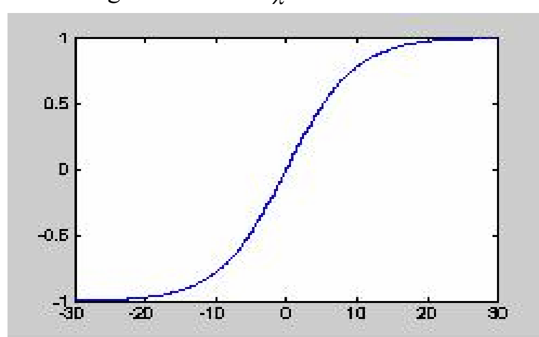

Fig.2 Sigmoid function

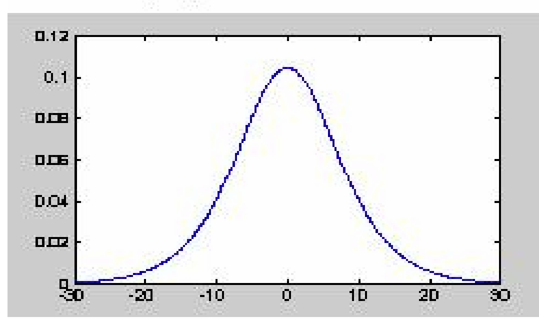

Fig 3 the differential of Sigmoid graphics

denotes the sensitive rate, k_c denotes Correctional factor of the angle error. In the equation 4, k_α denotes the scale coefficient, this parameter are effects of the input to the output generally. The value of this parameter can not exceed the max steering angle of the front wheel.

2) Lateral Displacement Control Model

Sensitive rate is not only influenced by the value of the lateral error, but also influenced by the angle error. The sensitive rate of lateral displacement to steering angle in Lateral Displacement Law has the relation with the angle error,, which can be expressed in the Equation 5.

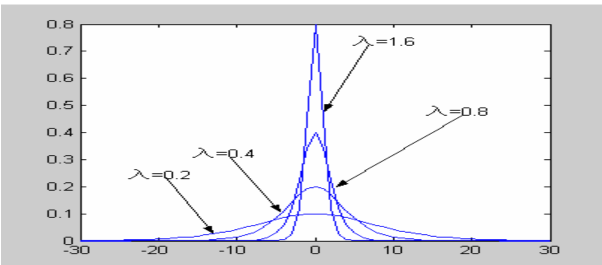

Fig.4 Differential function with different sensitive factor

$$g_{\alpha}(\alpha) = k_g \cdot \lambda_g \cdot e^{-\lambda_g \cdot \alpha} / (1 + e^{-\lambda_g \cdot \alpha})^2 + k_{gc} \text{ ..(5)}$$

Where,

λ_g Sensitive rate of Angle error to lateral displacement

k_g Sensitive coefficient of Angle error to lateral displacement

k_{gc} Correctional factor of Angle error to lateral displacement

And the function between the steering angle and lateral displacement can be expressed in the rate to input rate. This parameter has the very important effect to the design of the steering Equation 6.

$$f_{le}(le) = k_{le} \cdot (1 - e^{-g(\alpha) \cdot le}) / (1 + e^{-g(\alpha) \cdot le}) \text{ ...(6)}$$

Where k_{le} is the scale coefficient. The value of this parameter can not excess the max steering angle of the front wheel.

3) The overlap of these two kinds of models

The Equation 7 can be obtained from the overlap of these two kinds of models:

$$y = f_{le}(le) + f_{\alpha}(\alpha) \text{ ....(7)}$$

Equation 7 is the output of steering angle with lateral error and angle error as the input and without considering the

influences of the vehicle speed. In fact, Equation 7 describes steering behavior to track the target line. The graphics of the Equation 7 is as shown in the Figure 5. In the figure 6, axis X and Y respectively denote angle error and lateral displacement Axis Z denotes steering angle as the output. In the simulation, the angle error ranges from –15 to 15 degrees, and the lateral error ranges from –40 to 40 degrees, the output from –2 to 2. As shown in the Figure 5, as the increase of the two parameters, the steering angle as the output won't increase when the output exceeds a fixed value. In the opposite, when the absolute values of two parameters including lateral displacement and angle error are very low, steering angle changes sharply. This characteristic of the Equation 7 is according with the steering rules, and the design of the controller meets the requirement of the

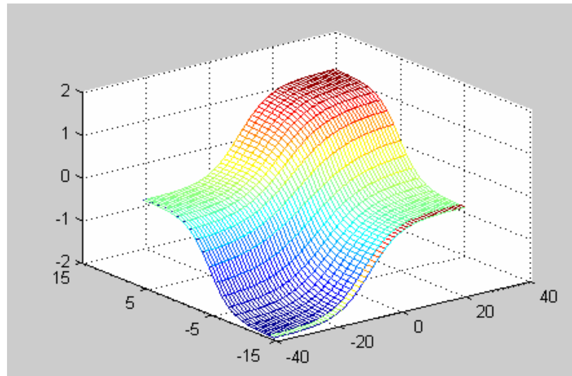

Fig.5 The 3D shape of the HS model

steering rules.

D. Parameters Adaptive Adjustment Algorithm

In the Equations mentioned above, the value of the parameters k_{λ} and k_g plays very important rolein in influencing HS control effects. In the paper, parameters adaptive adjustment algorithm is presented. This algorithm can adjust the parameters online real time, and its means are described as following:

Firstly, lateral displacement of 1st, 2th …… and *m*th control results are summed, which is described in the Equation 8.

$$E = \frac{1}{2}\sum_{i=1}^{m}(t_{j-i} - y_{j-i})^2 \text{ ....(8)}$$

Where

t_{j-i} Target lateral displacement at the moment of j-i.

y_{j-i} Real lateral placement in the road at the moment of *j-i*

Here we suppose that the vehicle runs on the straight road, when target is to track the lane, the target lateral displacement should always be 0.

Equation 8 can be rewritten as:

$$E_j = \frac{1}{2}\sum_{i=1}^{m}(y_{j-i})^2 \text{ ....(9)}$$

The target of parameters adaptive adjustment is to minimize control error *E*. It is obviously that if the vehicle can track the lane accurately, which means the real position of the vehicle and target position of the vehicle superpose, control error is the min. The negative feedback is used to minimize the control error, which express in the Equation 10:

$$\Delta K_j = -\eta \frac{\partial E_j}{\partial K_j} \quad \text{............................(10)}$$

The parameters adjustment can be realized, , which can be formulated into the Equation 11

$$K_j = K_{j-1} + \Delta K_j \quad \text{........................(11)}$$

From the Equation 7, 9, 10 and 11, the equation 12-16 can be obtained:

$$\frac{\partial E_j}{\partial k_{\lambda,j}} = y_{j-i} \cdot y'_{j-i} \quad \text{..............(12)}$$

$$\frac{\partial E_j}{\partial k_{\lambda,j}} = \left(f_\alpha(\alpha) + f_{le}(le)\right) \cdot \left(\frac{df_\alpha(\alpha)}{dk_\lambda} + \frac{df_{le}(le)}{dk_\lambda}\right) \quad \text{..(13)}$$

$$\frac{df_{le}(le)}{dk_\lambda} = 0 \quad \text{...................................(14)}$$

$$\frac{df_\alpha(\alpha)}{dk_\lambda} = k_\alpha \frac{-2 \cdot e^{-\lambda_\alpha(\alpha)\cdot\alpha}}{\left(1+e^{-\lambda_\alpha(\alpha)\cdot\alpha}\right)^2} \frac{\lambda_c \cdot e^{-\lambda_c\cdot\alpha}}{\left(1+e^{-\lambda_c\cdot\alpha}\right)^2} \quad \text{.(15)}$$

$$\frac{\partial E_j}{\partial k_{\lambda,j}} = \left(f_\alpha(\alpha) + f_{le}(le)\right) \cdot k_\alpha \frac{-2 \cdot e^{-\lambda_\alpha(\alpha)\cdot\alpha}}{\left(1+e^{-\lambda_\alpha(\alpha)\cdot\alpha}\right)^2} \frac{\lambda_c \cdot e^{-\lambda_c\cdot\alpha}}{\left(1+e^{-\lambda_c\cdot\alpha}\right)^2} \quad (16)$$

Parameters k_λ and k_g play a very important role in influencing the control effects of HS Control Algorithm.

The formulae of parameters k_λ and k_g adaptive adjustment are respectively expressed in the equation 17 and 18:

$$K_{\lambda,j} = K_{\lambda,j-1} + \eta \cdot \left(f_\alpha(\alpha) + f_{le}(le)\right) \cdot k_\alpha \frac{2 \cdot e^{-\lambda_\alpha(\alpha)\cdot\alpha}}{\left(1+e^{-\lambda_\alpha(\alpha)\cdot\alpha}\right)^2} \frac{\lambda_c \cdot e^{-\lambda_c\cdot\alpha}}{\left(1+e^{-\lambda_c\cdot\alpha}\right)^2} \quad \text{...(17)}$$

$$K_{g,j} = K_{g,j-1} + \eta \cdot \left(f_\alpha(\alpha) + f_{le}(le)\right) \cdot k_{le} \frac{2 \cdot e^{-g(\alpha)\cdot\alpha}}{\left(1+e^{-g(\alpha)\cdot\alpha}\right)^2} \frac{\lambda_g \cdot e^{-\lambda_g\cdot\alpha}}{\left(1+e^{-\lambda_g\cdot\alpha}\right)^2} \quad \text{.(18)}$$

IV. SIMULATION

To evaluate the performance of HS Control Algorithm, the simulation has been made and three controllers have been compared. The controllers are respectively designed based on three algorithms including PID, LQ, and HS Control Algorithms. The linear simplified model only containing lateral and yaw motion has been used in the simulation, which has been proved to be able to measure the effects of controllers on lateral control by many authors. [7][8]

Two tests have been simulated in this paper: one is Lane-changing test, as shown in the Fig. 6; another is slalom test as shown in the Fig.7. The vehicle speed is fixed at 30m/s, about 67.5miles per hour. The simulation results show that HS Control Algorithm as well as two other algorithms can finish lateral control and the control effects of HS algorithm are similar to LQ Algorithm while they are better than those of PID Algorithm for less lateral displacement. And it is due to the nonlinearity of HS algorithm and the character that HS algorithm is more sensitive to the small error.

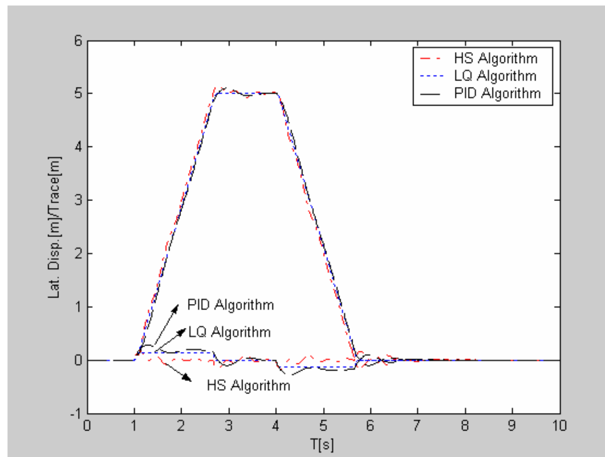

Fig.6 Simulation on lane-changing test

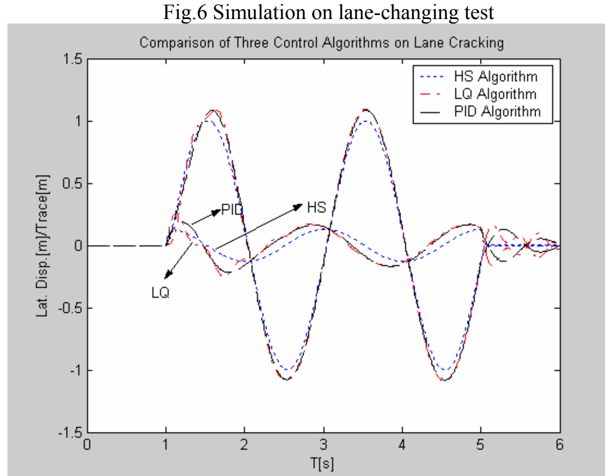

Fig.7 Simulation on slalom test

V. EXPERIMENT

The experiment is performed with a Jetta car. Fig.8 shows the structure of the machine vision system and the steering system. The machine vision system in the prototype includes a camera, image adaptor and the road lane marker identification algorithm. Machine vision system provides with the two input parameters. The HS algorithm makes decisions and sends the steering command to the steering actuator through the I/O adaptor, and front wheel will be driven by the steering motor. The response of the vehicle will be feedback to the HS controller by the machine vision system. So there's no other sensor used to directly detect the front wheel steering angle response. The machine vision in the system serve to provide both road information and feedback information . This is very much like the human driver does when he check the road with his eye and no other sensors needed to tell him the angle of the front wheels.

Fig.9 and Fig.10 show the results of the experiment. Fig.9 is the record of lateral displacement, angle error and vehicle speed. Fig.10 is the records of lateral displacement and angle error at the front wheel. As shown in the Fig.9, the road information from the machine vision changes greatly, which means from -30 to 30 cm. The angle error varies from -5° to 0°, but the variety of controller output is quite small (it vary from 0rad to 0.08rad/4.57°, and 60% of the output steering angle is less than 0.03rad/1.7°). In the controller the threshold of the steer action is 0.03rad/1.7°, so there is less than 40% of the operation time do the steering actuator need to take action. This is good for the steering actuator. The lateral displacement at the point where the camera mounted is less than 0.1 meters, which also shows the stability of the HS controller..

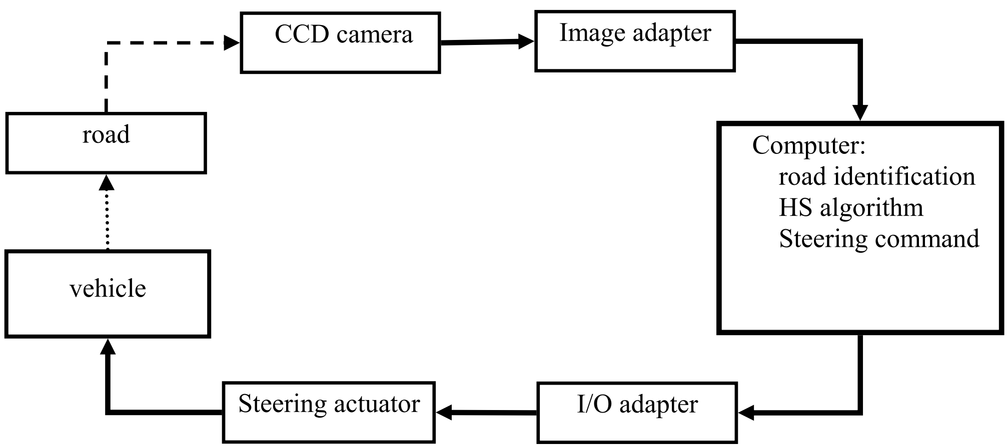

Fig. 8 The structure of the experiment platform

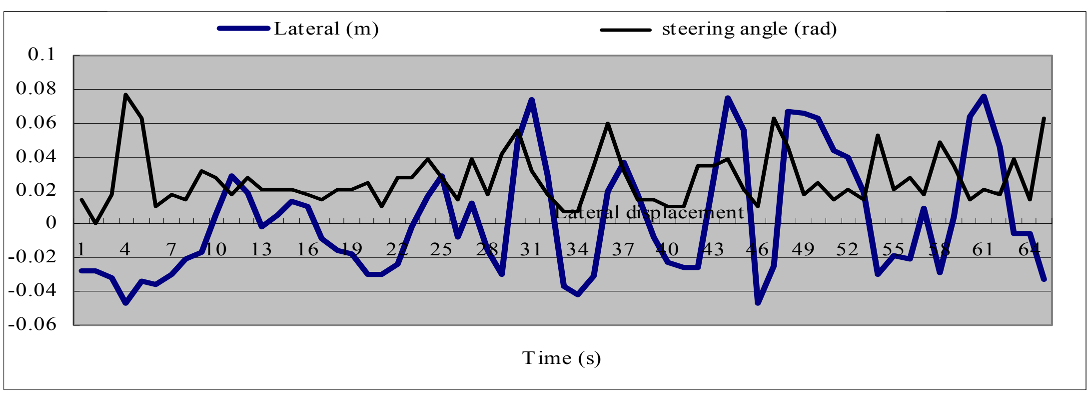

Fig.9 Information from the onboard machine vision system and speed
The lateral displacement at the looking-forward point in image

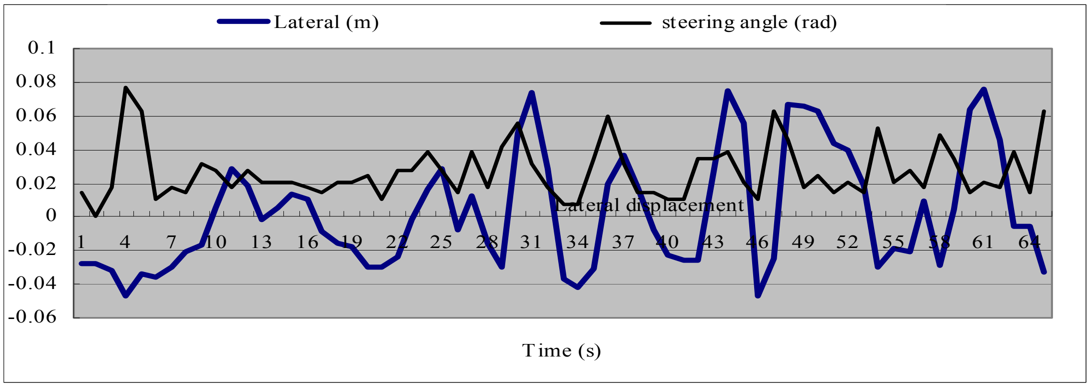

Fig.10 The output of the HS controller and lateral performance
The lateral displacement at the looking-forward point on road

VI .CONCLUSION

From the results of both the simulation and the experiments, this algorithm can realize the steering control of the vehicle and have good performance under the condition of the disturbance existing and the changing of the vehicle speed. The prototype vehicle is Jetta car. Machine Vision and electronic-control steering system are installed in it. The experiments have been performed in the low speed, middle speed, middle speed and high speed. The results show that Human Simulating controller has good performance and stability even the input information has a lot of noise. In the experiments, the stable vehicle speed is 150km/h (about 94 mile per hour), while the max vehicle speed is up to 172km/h (about 108 mile per hour).

APPENDIX

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