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An Investigation into Objective Measurement Methods of Vehicle Performance

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Abstract: Reliable methods for evaluating vehicle handling and stability are very necessary for the research of the driving safety. In order to overcome the reliance on a trained driver and associated subjective judgment, this paper proposed an objective measurement method for handling and stability evaluation. Based on optimal control theory, the closed-loop system is used during the road test combining virtual simulation and road test. Vehicle and driver model are analyzed. The road test platform is built, the error of lateral displacement is measured, and the affecting factors are analyzed, and the error is reduced through adopting the compensation factor. The pre-given trajectory is obtained through gathering the real trajectory by the driver in typical test, and is inputted into the human-vehicle-road system. Driver steering input under typical conditions is obtained through optimization algorithm, the uncertainty of driver and proving ground is coupled with steering angle. The test with the steering angle is carried out through the steering robot on the proving ground, and results are compared with the results of driver test. The results show that the measurement method has finished the task successfully in many tests and obtained satisfactory effect.

Keywords: objective measurement, handling stability, driver model, closed-loop, control robot

1 Introduction

With the rapidly development of electronic system, the driver assisting systems enhance vehicle-safety by changing vehicle operation under dangerous working condition. The selections of test methods are very important to verify and evaluate vehicle safety performance. Open-loop and closed-loop test are used to evaluate the vehicle performance. In open-loop tests, the inputs of tests are given in advance, and testing results are objective and can be repeated. However, the human interaction is ignored in those tests. In closed-loop tests, the inputs of tests are given by professional drivers, and testing results can truly reflect the vehicle performance. But, it cannot be widespread application during the evaluation of vehicle because of the safety concerns and consistency of driver. With the computer technology development, the application of simulation can be trend of testing vehicle performance. It's useful to access the performance of vehicle at the initial stage of the design work, more and more research organizations and companies do efforts to explore method to evaluate the vehicle, Abe proposed atheoretical evaluation method for vehicle handling qualities using a preview control model of driver[1]. Harada with a similar driver model, evaluated the handling qualities for lane changes or exposure to crosswind[2]. Modjtahedzadehand Hess proposed analytical method for vehicle performance assessment based on a theoretic model of steering operate behavior[3]. But It's not accurately to evaluate the vehicle on the proving ground because of the inaccurate modeling of vehicle, driver and varying of the driving conditions.

In order to accurately measure the vehicle performance, this paper describes analytical test method of handling qualities of vehicles on the proving ground. The goal of the presented research is to develop objective measures for the assessment of the vehicles handling stability. Such methodology has its potential in enabling the handling evaluation also without considering the driver and road environment and in acceleration the assessment of the existing vehicles.

This paper first describes human-vehicle-road closed-loop system inSection2, a reliable vehicle model is calculated with test data, and the driver-vehicle system structure and the driver model are described and analyzed. In Section 3, a new measure method of handling stability is proposed, and the experiments are designed to describe how to effectively transfer human control strategy to the steering robot. In Section 4, based on the proposed test method of handling stability, the proving ground tests are carried out to verify the validity of the method with actual driver. Finally, the result is summarized in Section 5.

2 Human-vehicle-road clsed-loop system

In order to get the optimal control profile, it is necessary to study the optimal control model of the test system. The key problem of optimal control is how to find an optimal control rule to make the system optimal work according to dynamic characteristics of the controlled system under some constraints. That is, the allowed control rule is found to make the performance index J get maximum or minimum when the system transfer toward desired state frominitial state. The system-state equations is $X(t)=f[x(t),u(t),t]$, $x(t_0)=x_0$, objective ranges: $S=\{x(t_f):x(t_f)\in R^n,\psi[x(t_f),\ t_f]=0\}$, $x(t_f)$ is n-dimensional state vectors, $u(t)$ is p-dimensional control vectors, $u(t)$ is continuous in sections in $[t_0,t_f]$, the performance function is $J=\theta[x(t_f),\ t_f]+\int \mathrm{F}[x(t),u(t),t]dt$. Based on the premise that the performance function can obtain optimal performance, it need to find an allowable control $u(t)\in u$ to make the system $x(t)$ transfer toward desired state $x(t_f)\in S$ from initial state x_0 under some constraints. $u^*(t)$ is called the optimal control, $x^*(t)$ is called the optimal trajectory, $J^*=J[u^*(t)]$ is called the optimal performance index.

According to driver characteristics and optimal control theory, Weir and McRuer researched the structure of the human-vehicle system[4], the compensation driver model was presented, in which the factors of reaction time and lag time were taken into consideration. However, the preview characteristics were not considered in these studies. MacAdam and Guo put forward some driver models in view of optimal preview closed-loop control based on the feedback of vehicle states[5, 6]. Taking the driver preview into account, this paper assumes that the closed-loop structure is feedback system, as described in Figure 1, which uses vehicle lateral displacement, lateral velocity, lateral acceleration and differential of the lateral acceleration as feedback signals, and the characteristics of driver including preview time are important. Mclean and Hoffman experimentally studied the effects of preview on driver steering performance on straight road and suggested an optimum preview time is approximately 1.5s[7]. Figure 1 shows the basic driver/vehicle system to be discussed.

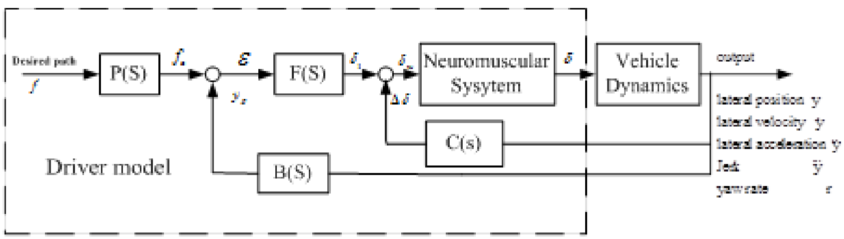


Figure 1. Human-Vehicle-Road System

As shown in Figure 1, the driver model calculates the steering angle according to the feedback information from the states of vehicle. The characteristics of a good driver/vehicle system can be described as regulating the track of the vehicle y to follow the desired path f over a broad frequency range while minimizing sensitivity to disturbances and variations in the characteristics of the vehicle or driver.

2.1 Driver model

A driver model usually includes two essential components, as shown in Figure 2. The first of these components represents a time lag which consists of nervous system delay and muscular system delay. These lags are approximated as $e^{-t_d s}/(t_h s+1)$ in terms of delay time and the first order lag system. It can be assumed that these lags do no change due to the intention of driver, and in fact, the values of t_d and t_h remain virtually unchanged regardless of operating conditions. Accordingly, all discussions in the following sections will use constant t_d and t_h .The second components ($w_1 f-w_2 y+w_3\dot{y}+w_4\ddot{y}+w_5\dddot{y}$) which denotes leading or predictive action of the driver, which means that the driver controls the vehicle by future values of target signals and present states of vehicle. The driver adjusts the values of parameters w_1,w_2,w_3,w_4 *and* w_5 to realize desired driver-vehicle system characteristics according to the desired track and vehicle [8].

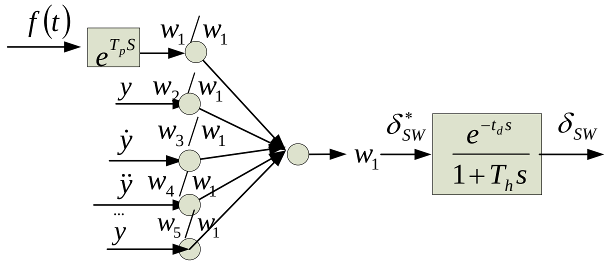


Figure 2. Improved POSANN driver model

2.2 Vehicle model

The test vehicle is so complex that cannot be used directly to get the parameters of the system. So, it is need to get the characteristic of test vehicle under certain conditions. A mathematical model of vehicle system with 2 freedom degrees will be got from test vehicle, and the parameters (G_{ay}, T_1, T_2, T_{y1}, T_{y2}) of the model can be identified according to data of the test vehicle. As shown in Figure 3, the impulse signal is used to obtain the lateral acceleration on the proving ground. The same input is sent to the vehicle model to calculate the lateral acceleration. Using the error between a_y and $\tilde{a}_y$, an objective function is created for optimizing parameters of vehicle model. The rising and falling time of the impulse signal are both 0.1 second.

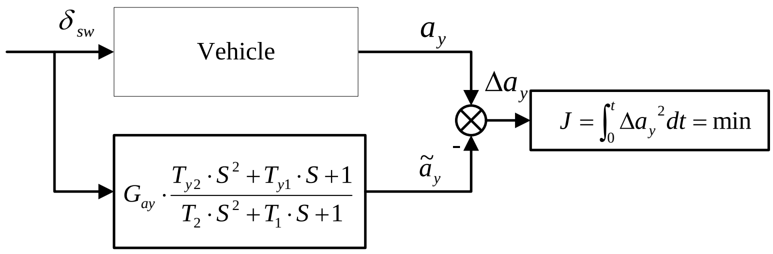


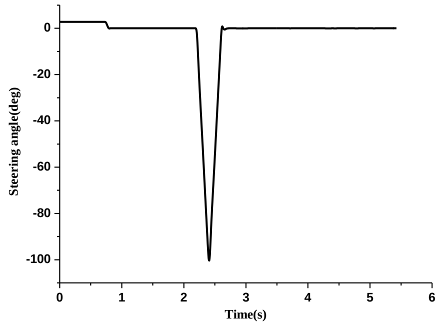
Figure 3.The identification process of vehicle parameters

The lateral dynamics property of vehicle varies with speed. Hence it is necessary to study the relationship between vehicle speed and all the parameters of vehicle model. By describing the functional relationship between the parameters of vehicle model with speed, as shown in equation (1), the inputs and outputs of test vehicle under varied speeds, which are measured on the proving ground, are applied to calculate the parameters for this function.

$$\begin{cases} G_{ay} = a_1 + a_2 \cdot V + a_3 \cdot V^2 \\ T_1 = b_1 + b_2 \cdot V + b_3 \cdot V^2 \\ T_2 = c_1 + c_2 \cdot V + c_3 \cdot V^2 \\ T_{y1} = d_1 + d_2 \cdot V + d_3 \cdot V^2 \\ T_{y2} = e_1 + e_2 \cdot V + e_3 \cdot V^2 \end{cases} \quad (1)$$

2.3 Identification test

It is important to choose the input to stimulate the vehicle frequency characteristic for the accuracy of vehicle parameters. In this article, a pulse is chosen, as shown in Figure 4, taking 0.2 seconds to rise. The signal input is tested by the driver, and the lateral acceleration is collected. At the same time, the same angle is input to the two-freedom vehicle model. An off-line identification method is applied in researching handling and steady vehicle model at one speed. The result is shown in Figure 5.



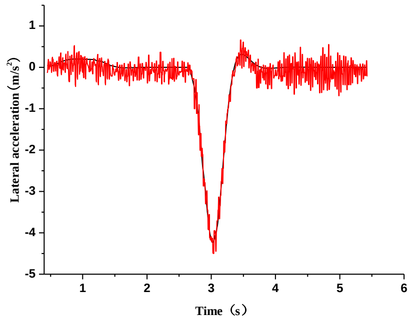
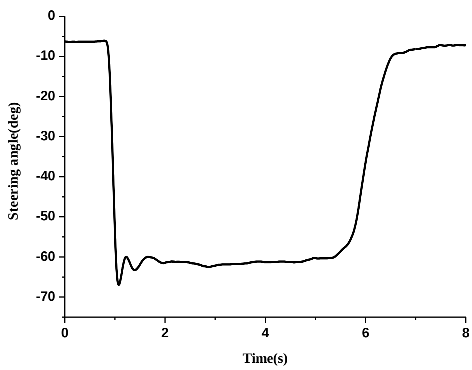


Figure 4.Pulse signal of steering angle

Figure 5. The identification result of lateral acceleration

2.4 Model validation

In order to verify the result consistency at the same speed, the step test is chosen as the validation test. The yaw rate and lateral acceleration as the outputs are got during the step test on the proving ground, and compared with the result of simulation, as shown in Figure 6 and Figure 7, the results shows that test results are consistent with simulation analysis, which demonstrates the validity of the model.



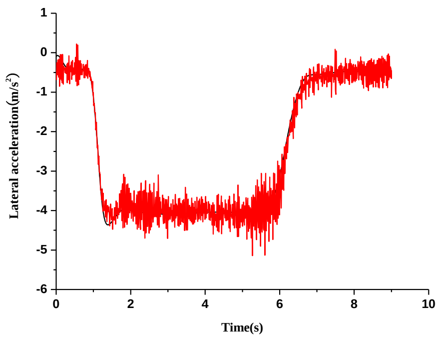
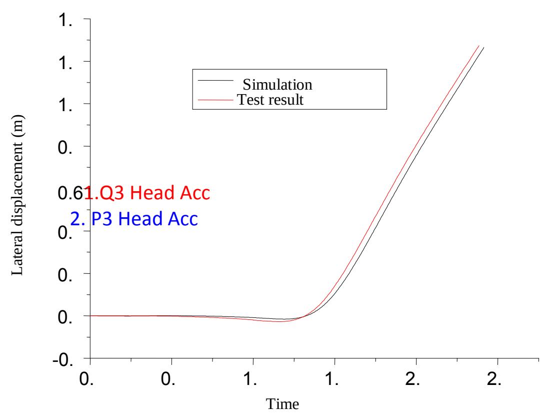


Figure 6. The step input of steering angleFigure 7. The comparison of test result and simulation



result

Figure 8.The comparison of test result and simulation result before compensation

The lateral displacement of calculation and the actual measurements are shown in Figure 8, the overall trend is similar. Since the 2-DOFs linear model has ignored the effect of lag non-linear, the non-linear damp and non-linear rigidity etc, at the same time the result is affected by the friction coefficient and the errors resulted from the measurement instrument, the result of calculation and the actual measurements is different slightly. It is necessary to find compensation factor to eliminate errors for obtaining more accurate data, the steering angle is changed through multiply the compensation factor, and the modified result is much closer to the real result as shown in Figure 9.

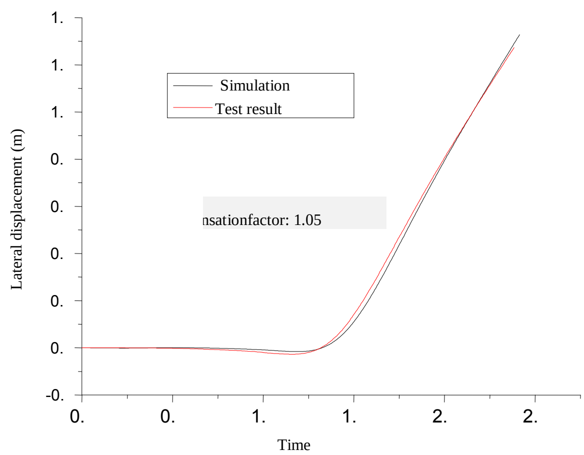


Figure 9.The comparison of test result and simulation result after compensation

3 The objective measure of test vehicle

The handling stability is an important indicator of vehicle, which is very important for driving safety. The accuracy of the objective evaluation is affected by the deviation of driver input in the handling stability test. The steering angle of driver is uncertainty, imprecision and non-repeatable, and lead to the bad traceability of result. The steering robot is used to control the vehicle instead of drivers for decreasing the negative effect of human driver. The control input of the steering robot is studied based on the vehicle-human-road closed-loop system in this paper. A new measure method is proposed, the structure is shown in Figure 10.

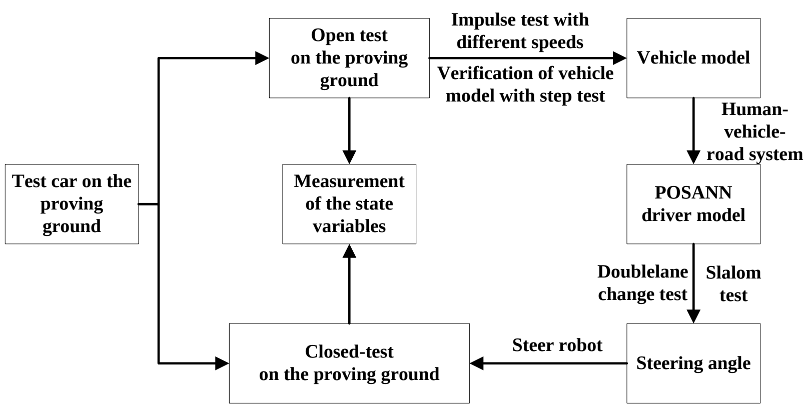


Figure 10.The measure process of handling stability test

Firstly, the vehicle model is obtained by open-loop test identification, the closed-loop system is built and optimized, and the ideal steering angle is calculated according to the input of road function. Secondly, the steering angle is inputted to the steering robot, the handling stability test is executed on the proving ground, the vehicle responses are collected through the measurement sensors.

The handling stability is affected by the typicalworkingconditions. Double-lane change test and slalom test are adopted, which are important test during the evaluation of vehicle handling stability. The handling performance is checked by rollover and sideslip condition, at the same time those test are used to subjective evaluation test. The site layout of test are shown in Figure 11 and Figure 12.

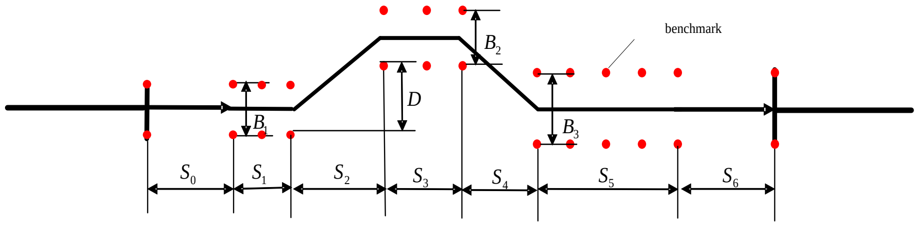


Figure 11.The site layout of double-lane change test

S_0=50m,S_1=25m,S_2=30m,S_3=S_4=25m,S_5=30m,S_6=415m.

Offset distance:D=3.5m.Benchmark width:B_1=1.1b+0.25,B_2=1.2b+0.25,B_3=1.3b+0.25.

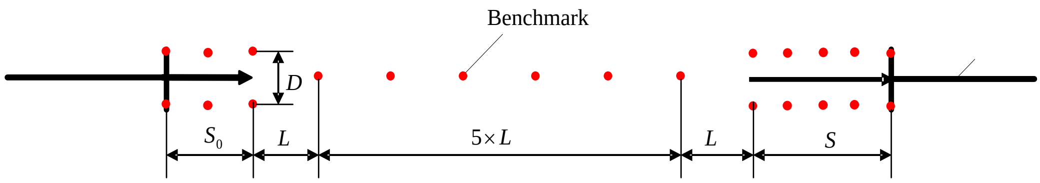


Figure 12.The site layout of slalom test

D=1.1*bm,S_0=50m,S=100m,L=30m,b:vehicle width.

Considering key factors such as speed, vehicle and driver's individual character in experiment, a desired trajectory is designed. Some drivers are chosen to execute the test with different speed. The driving routes of vehicles are recorded. The desired trajectory is analyzed as shown in Figure 13 and Figure 14.

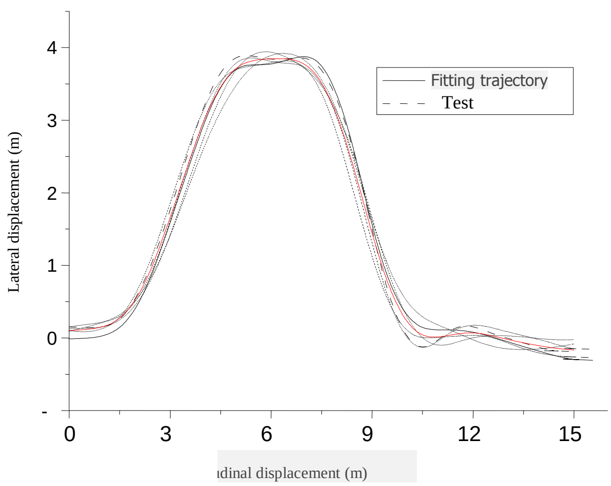


Figure 13.The fit trajectory and the measured trajectory of double lane change test

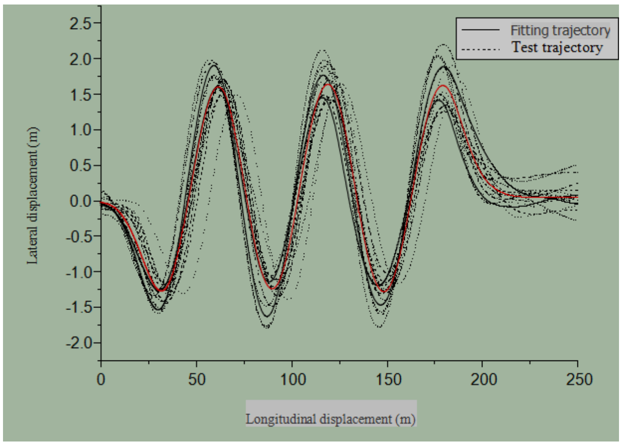


Figure 14.The fit trajectory and the measured trajectory of slalom test

The desiredtrajectory is input to the closed-loop system, the desired steering angles are got in the simulationexperiment, asshown in Figure 15 and Figure 16.

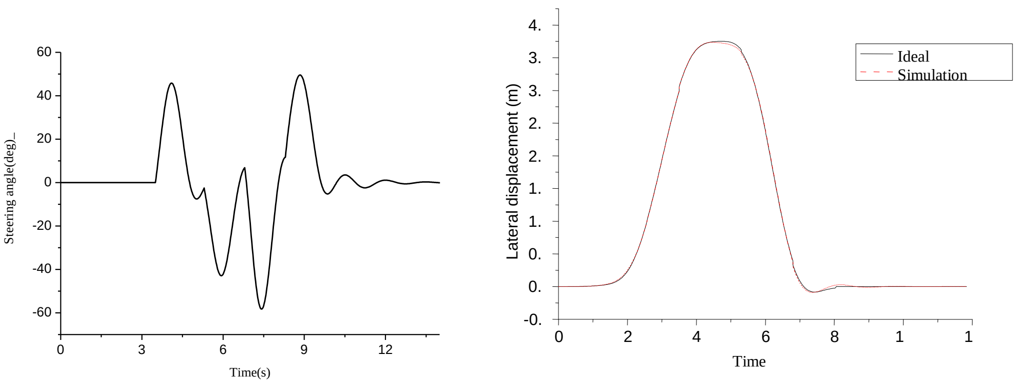


Figure 15.The steering angle and the lateral displacement of double lane change test

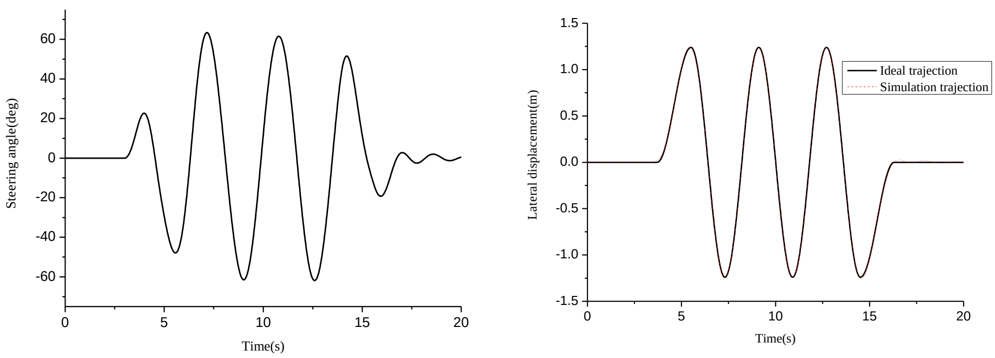


Figure 16.The steering angle and the lateral displacement of slalom test

4 The applications of objective measures

4.1 In-vehicle testing

A comprehensive series of objective evaluation measurements are taken on the Guangde proving ground. The experiments are designed in which one vehicle test is driven by four drivers. The vehicle is equipped with the steering robot, RT3002 and roll angle sensors. The measurements messages are indicated in Table1.

Table1.Summaryofmeasurements

Instrument	Mounting Position	Measurement
Steering Robot	Steering wheel	Steering wheel angle Steering wheel torque
RT3002	Center	Lateralacceleration Longitudinalacceleration Verticalacceleration Rollrate Yawrate Pitchrate
Based Station	Ground	Displacement
HL500	Both side of vehicle	Roll angle

The desired steering angles are input to the steering robot and the tests are done on the Guangde proving ground, the test results are shown in Figure 17 and Figure18. Results of the test indicated that vehicle did not bump markers and successfully completed the test.

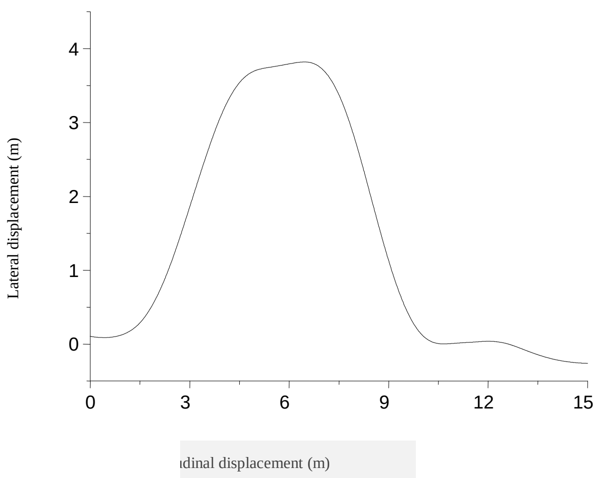


Figure 17.The trajectory of double lane change test

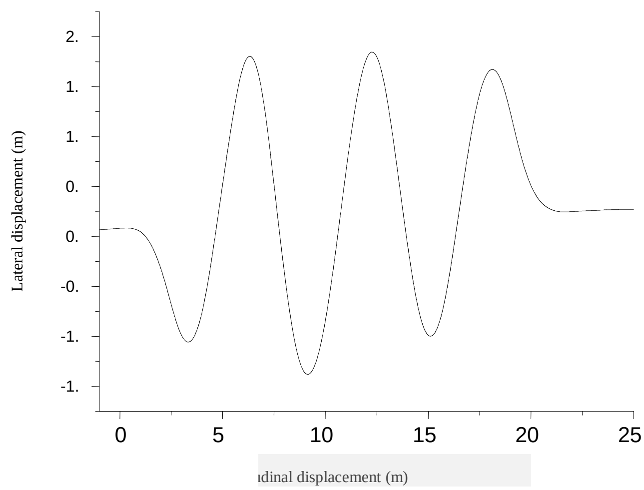


Figure 18.The trajectory of slalom test

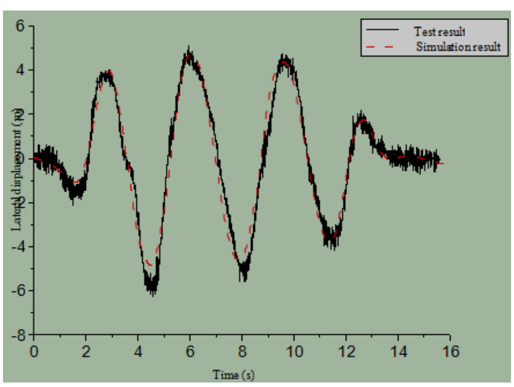


Figure 19.The lateral displacement comparison of test result and simulation result

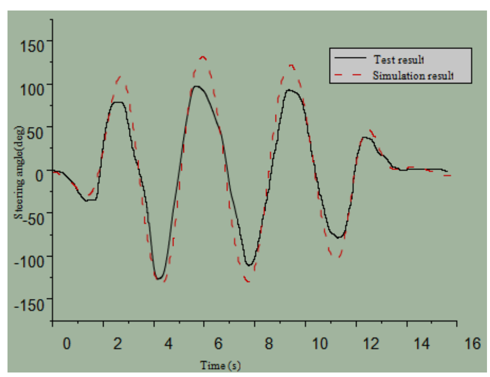


Figure 20.The steering angle comparison of test result and simulation result

In order to further verify the close-loop characteristic of the measure method, some experienced drivers are chosen and the test is carried out on the proving ground, comparison test completed successfully, the lateral displacement and steering angle of slalom test are recorded and compared with results of robot test, as shown in Figure 19 and Figure 20. The comparisons for the test result have shown that the accuracy of simulation results with respect to the actual measurement.

5 Conclusions

The study on the objective test of vehicle handling and stability is carried out. Based on the extensive reviews of the vehicle test methods, the human-vehicle-road closed test system can be used during the road test combining virtual simulation and road test. Vehicle model and driver model are analyzed. The road test platform is built, the error of lateral displacement is measured, then the error and affecting factors are analyzed, and the error is reduced through adopting the compensation factor. The pre-given trajectory is obtained through gathering the real trajectory by the driver. Driver steering input under typical conditions is obtained through optimization algorithm, the uncertainty of driver and proving ground is coupled with steering angle. The test with the steering angle is carried out through the steering robot on the proving ground, and results are compared with the results of real driver test. The results show that the test method has finished the task successfully in many tests and obtained satisfactory effect.

Acknowledgments

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