Research on measurement techniques of vehicle road safety

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Abstract: - Reliable methods for evaluating vehicle road safety are very necessary for the research of the driving safety. The test methods can be categorized into two kinds: virtual simulation and road test. These two kinds of approaches can evaluate vehicle safety efficiently on some level, but there are some shortcomings, which include the test accuracy and test efficiency. In order to overcome the shortcomings, in this paper, combining the benefits of those two methods, a novel test methodologies is developed. Based on 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. The results show that the proposed test method can effectively provide convincing results of the driving safety with a high accuracy under a variety of driving conditions and provides better guidance for vehicle safety research.

Key words: measurement method, road safety, driver model, closed-loop, 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 [1]. 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 [2]. 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 [3]. Abe proposed a theoretical evaluation method for vehicle handling qualities using a preview control model of driver[4]. Harada with a similar driver model, evaluated the handling qualities for lane changes or exposure to crosswind[5]. Modjtahedzadeh and Hess proposed an analytical method for vehicle performance assessment based on a theoretic model of steering operate behavior[6]. 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 an 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 in Section 2, a reliable vehicle reference 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 closed-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 [7]. 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 from initial 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[8], 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[9, 10]. Taking the driver preview into account, 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[11]. Fig.1 shows the basic driver/vehicle system to be discussed.

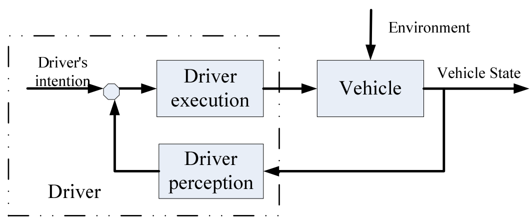


Fig. 1 Human-Vehicle-Road System

As shown in Figure 1, the driver obtains the feedback information from the states of vehicle. The characteristics of a good driver can be described as regulating the track of the vehicle y to follow the desired path over a broad frequency range while minimizing sensitivity to disturbances.

2.1 Driver control system

A driver control system usually includes three essential time components, as shown in Fig. 2. The first of these components represents perception, obtains the feedback information from the states of vehicle and environment. The second of these components represents decision, which include a time lag which consists of nervous system delay and muscular system delay. It can be assumed that these lags do no change due to the intention of driver, and in fact, the values of nervous system delay and muscular system delay remain virtually unchanged regardless of operating conditions. The third components represents execution 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[12].

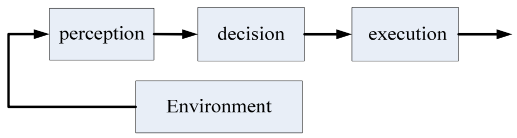


Fig. 2 Driver control system

In this paper, the driver model is based on the so-called the preview-follower theory. The driver model modifies the controller parameters according to the generalized error and according to certain criteria, or generates an auxiliary input signal, so that a functional index of the generalized error reaches a minimum [13]. When the characteristics of the controlled object are asymptotically approximated by the characteristics of the reference model, the generalized error tends to be minimal or decreases to zero, and the trajectory tracking process ends. It is a widely used vehicle dynamics state to calculate driver operator characteristics for use in vehicle dynamics test. The general form of the formula that holds for given values of the latera dynamics of the vehicle reads

$$Sw = \lambda(w1, w2, w3, k)$$

where

Sw the steering angle

λ gain coefficient

w1 lateral displacements difference factor

w2 lateral velocity factor

w3 lateral acceleration factor

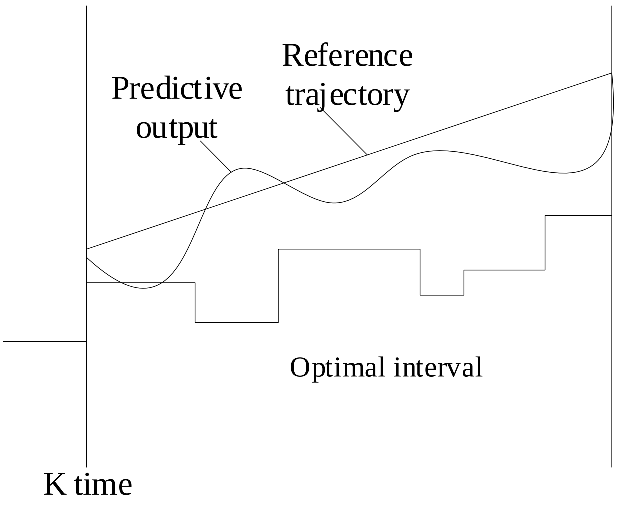
k lateral acceleration difference factor

Driver control model is a rolling optimization control algorithm. Under certain constraints, the future control effect can be obtained by optimizing a certain performance index. The optimized performance index is related to the future behavior of the system. For example, when tracking the desired trajectory, the minimum variance of the predicted output and the expected trajectory on the future sampling node is usually selected as the performance index.

At the instant of each sampling, the scope of the model predictive control optimization is limited to determining the future control effect by solving the optimal value of the performance index during the period in a certain period of time. When the system rolls to the next sampling instant, the optimization period also moves forward. Rolling optimization is the fundamental point that model prediction control is different from traditional optimization control algorithm. It is not a global performance indicator [14], but has performance indicators corresponding to each time period at each moment, so through real-time calculation it canf effectively reduce the influence of model mismatch, thus enhancing the robustness of the control algorithm.

The rolling optimization process determines the future control effect by optimizing the performance indicators in the interval at the moment K, and adopts the corresponding control strategy at the moment K. At the moment $K+1$, the optimization interval also advances a sampling period, recalculates the optimal value of the performance index during the sampling period, and determines the future control effect. The rolling optimization process is shown in Fig 3.

Fig. 3 rolling optimization process diagram



For traditional control algorithms, even if there is an accurate mathematical model, it often requires a large amount of calculation, which puts high demands on computer hardware. At the same time, when the vehicle is driving on the road, it is often subject to lateral wind and road unequal external interference, which makes the control algorithm based on off-line optimization low in robustness and control precision difficult to guarantee. Based on these factors, the intelligent path prediction control algorithm designed in this paper establishes the steering control system of the vehicle, so that the vehicle can follow the path well.

2.2 Vehicle reference model and identification procedures

Since the vehicle has many degrees of freedom and high coupling, it is a very complicated work to establish an accurate vehicle dynamics model [15]. 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 the vehicle, and the parameters of the model can be identified according to data of the vehicle. As shown in Fig. 4, the typical 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.

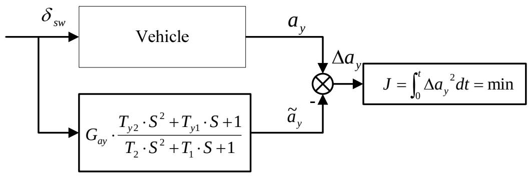


Fig. 4 the identification process of vehicle parameters

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.

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

where G_{ay} is the vehicle lateral acceleration gain to steering wheel angle, T_1, T_2, T_{y1}, T_{y2} are the parameters which present vehicle's dynamic response property, those parameters can be calculated using V in the fitting methods.

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 Fig. 5, 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 Fig. 6.

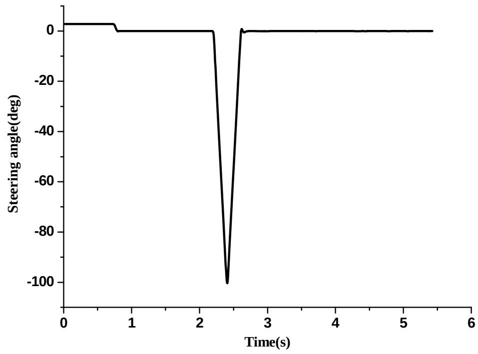


Fig. 5 pulse signal of steering angle

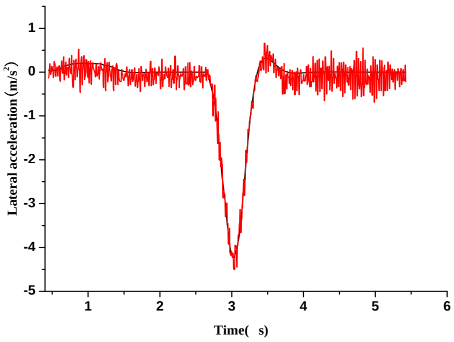


Fig. 6 The identification result

2.3 Model validation procedures

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 Fig. 7and Fig. 8, the results shows that test results are consistent with simulation analysis, which demonstrates the validity of the model.

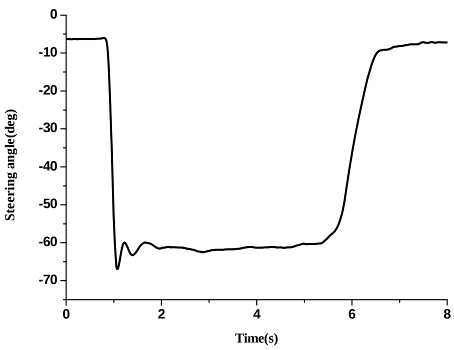


Fig. 7 The step input of steering angle

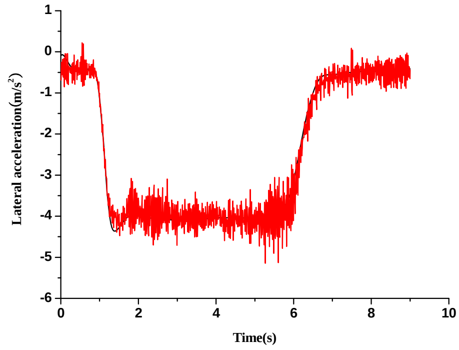


Fig. 8 The comparison of test result and simulation result

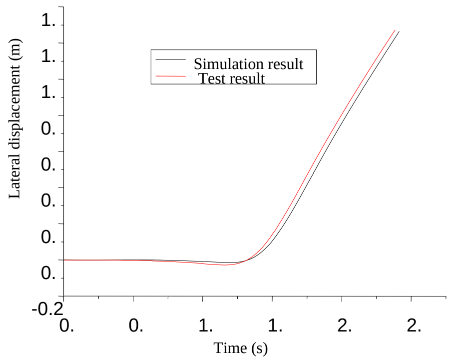


Fig. 9 the comparison of test result and simulation result before compensation

The lateral displacement of calculation and the actual measurements are shown in Fig. 9, 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 Fig. 10.

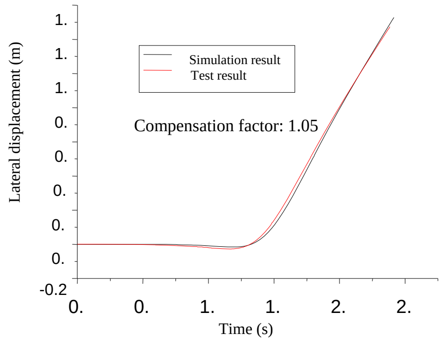


Fig. 10 the comparison of test result and simulation result after compensation

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 [16]. 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 Fig. 11.

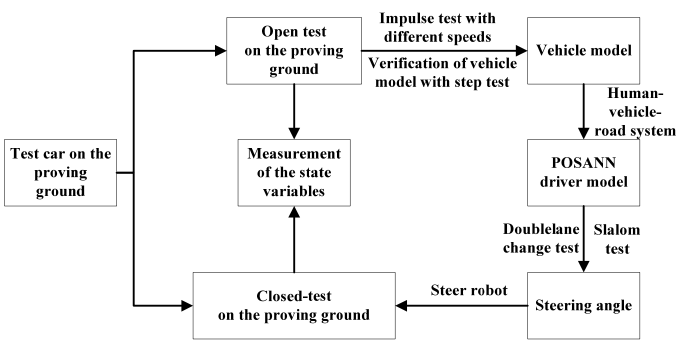


Fig. 11 the measure process of handling stability test

Firstly, the vehicle model obtained from the open-loop test is placed in the Human-Vehicle-Road closed-loop operation system, and the ideal road function is taken as the input of the Human-Vehicle-Road closed-loop system, it ignore the uncertainty of the driver and is regarded as the output of an ideal and experienced tester, the steering wheel angle of the corresponding path is obtained through the closed-loop simulation test, the ideal steering wheel angle is input into the real vehicle steering robot, the handling stability test is executed on the proving ground, and the vehicle status information is obtained through the measurement of the sensor; Finally, based on the analysis of vehicle state information, the closed-loop characteristics of Human-Vehicle-Road are evaluated.

According to the driving task requirements, the handling stability is affected by the typical working conditions. Double-lane change test and slalom test are adopted [17], 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 is shown in Fig. 12 and Fig. 13.

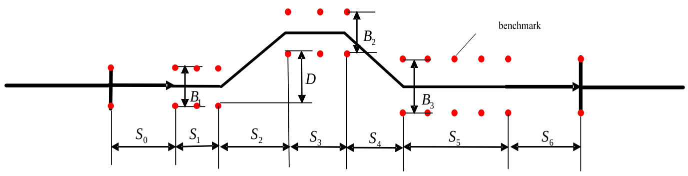


Fig. 12 the site layout of double-lane change test

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

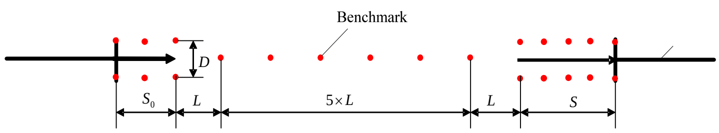


Fig. 13 the site layout of slalom test

$D = 1.1 * bm$, $S_0 = 50m$, $S = 100m$, $L = 30m$, 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 Fig. 14 and Fig. 15.

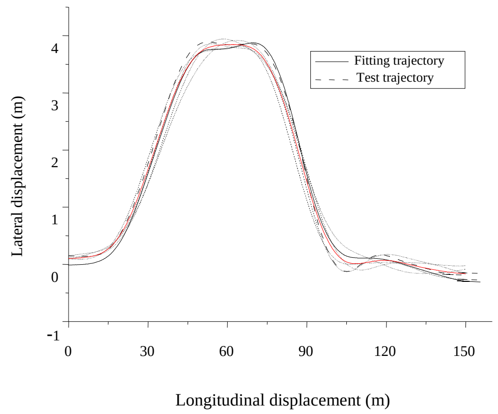


Fig. 14 the fit trajectory and the measured trajectory of double lane change test

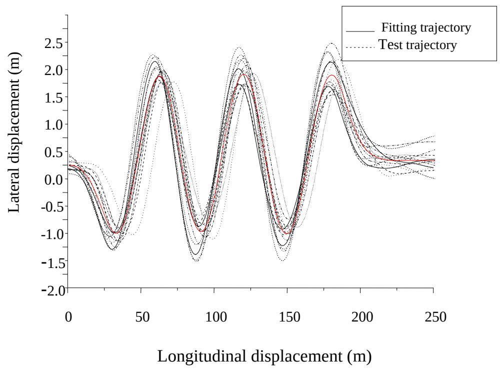
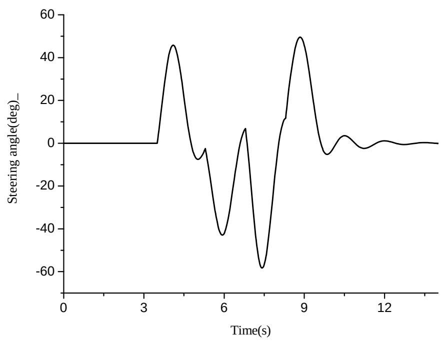


Fig. 15 the fit trajectory and the measured trajectory of slalom test

The desired trajectory is input to the closed-loop system, the desired steering angles are got in the simulation experiment, as shown in Fig. 16 and Fig. 17.



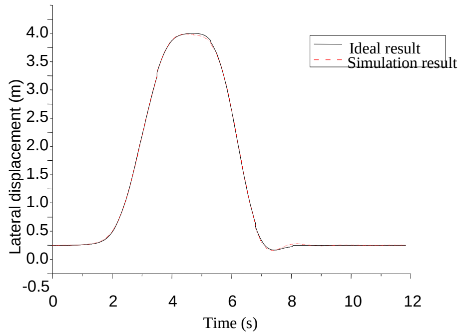
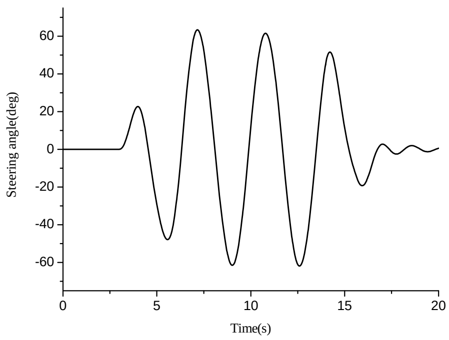


Fig. 16 the steering angle and the lateral displacement of double lane change test



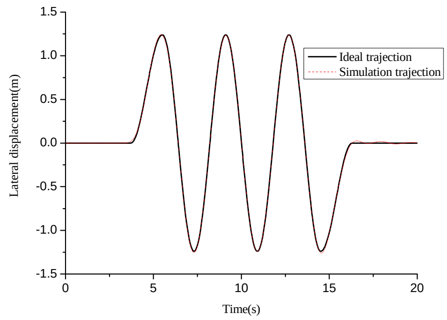


Fig. 17 the steering angle and the lateral displacement of slalom test

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 Summary of measurements

Instrument	Mounting Position	Measurement
Steering Robot	Steering wheel	Steering wheel angle Steering wheel torque
RT3002	Center	Lateral acceleration Longitudinal acceleration Vertical acceleration Roll rate Yaw rate Pitch rate
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 Fig. 18 and Fig. 19. Results of the test indicated that vehicle did not bump markers and successfully completed the test.

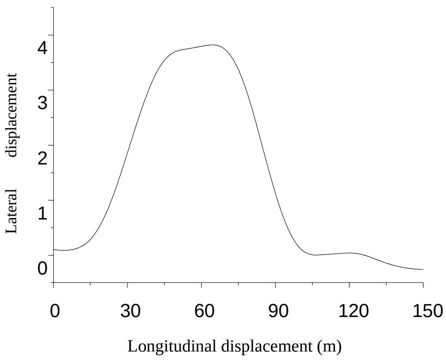


Fig. 18 the trajectory of double lane change test

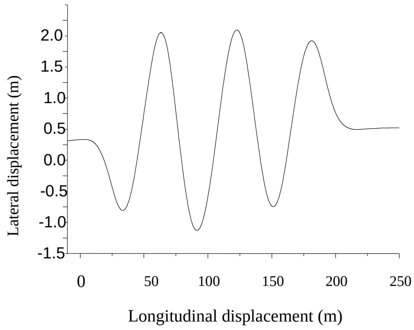


Fig. 19 the trajectory of slalom test

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 Fig. 20 and Fig. 21. The comparisons for the test result have shown that the accuracy of simulation results with respect to the actual measurement.

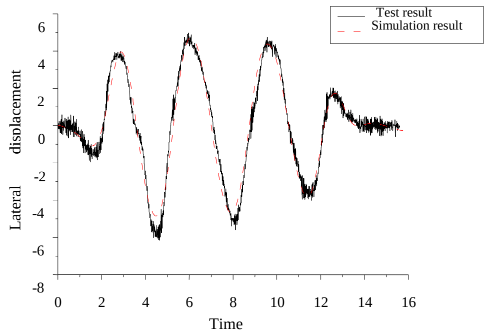


Fig. 20 the lateral displacement comparison of test and simulation

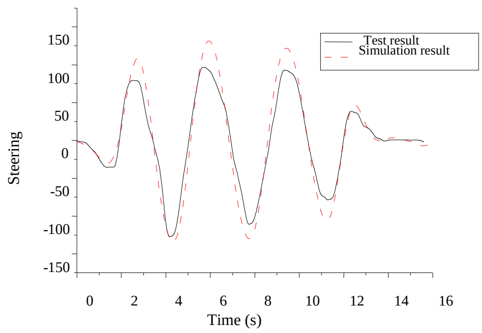


Fig. 21 the steering angle comparison of test and simulation

5. Conclusion

The study on the measurement method of vehicle road safety 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.

Acknowledgment
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References:

[1] Kesting A , Treiber M , Helbing D . Enhanced intelligent driver model to access the impact of driving strategies on traffic capacity[J]. Philos Trans A Math Phys Eng Sci, 2010, 368(1928):4585-4605.

[2] Jiang Z Y, Jiang W. the Open and closed loop evaluation of reference models[J]. BEIJING AUTOMOTIVE ENGINEERING, 2008(3):14-18.

[3] Sun X Y. Research and application of object-oriented vehicle dynamics system modeling [D]. Kunming university of science and technology, 2002.

[4] Abe, M. Theoretical Prediction of Subjective Vehicle Handling Evaluation[J]. Proc. of XVIII FISITA, Hamburg, Germany. 1980.

[5] HARADA, H., IWASAKI, T. Stability criteria and objective evaluation of a driver-vehicle system for driving in lane change and against crosswind[J]. Vehicle system dynamics. 1994, 23(S1): 197-208.

[6] Modjtahedzadeh, A., Hess, R. A model of driver steering control behavior for use in assessing vehicle handling qualities[J]. Journal of dynamic systems, measurement, and control. 1993, 115(3): 456-464.

[7] Jiang B N. On the least-squares method[J]. Computer Methods in Applied Mechanics & Engineering, 1998, 152(1):239-257.

[8] McRuer, D. T., Jex, H. R. A review of quasi-linear pilot models[J]. Human Factors in Electronics, IEEE Transactions on. 1967, (3): 231-249.

[9] Guo, K., Fancher, P. S. Preview-follower method for modelling closed-loop vehicle directional control[J]. 1983.

[10] MacAdam, C. C. Application of an optimal preview control for simulation of closed-loop automobile driving[J]. 1981.

[11] McLean, J. R., Hoffmann, E. R. The effects of restricted preview on driver steering control and performance[J]. Human Factors: The Journal of the Human Factors and Ergonomics Society. 1973, 15(4): 421-430.

[12] Cheng, Y, Guo, K. Driver Model Based on Error Elimination Algorithm and Its Application to ADAMS [D]. 2003.

[13] Diao S F, Wang Y. Analysis of focus problems and social governance of driverless cars [J]. China Statistics, 2017, (9): 58-59.

[14] Du Y. Functional requirements and related technical points of urban rail transit unmanned system[J].Urban rail transit research, 2017, 20 (51): 14-17.

[15] Deng G X, Deng C, Wang Y M, et al. Design and Simulation of radar sensor unmanned tracking

controller [J]. Journal of Chongqing Normal University: Natural Science Edition, 2017, 53 (3): 128-134.

[16] Chakroborty P , Kikuchi S . Evaluation of the General Motors based car-following models and a proposed fuzzy inference model [J]. Transportation Research Part C (Emerging Technologies), 1999, 7(4):209-235.

[17] Huang J , Tan H S , Bu F , et al. An investigation on driver trajectory planning behaviors based on double lane change vehicle test data[C]// International IEEE Conference on Intelligent Transportation Systems. IEEE, 2011.