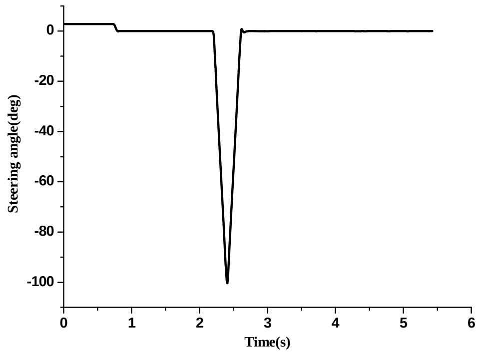


Fig. 5 pulse signal of steering angle

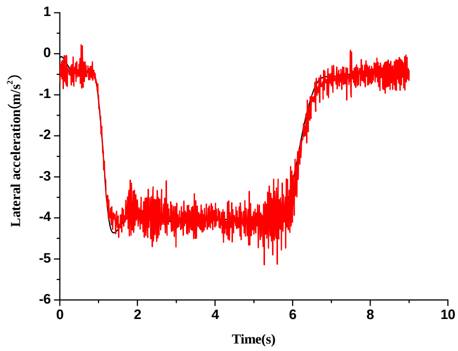


Fig. 8 The comparison of test result and simulation result

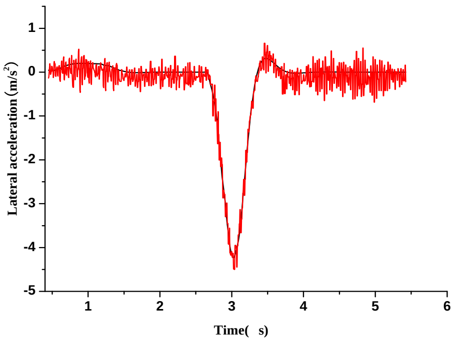


Fig. 6 The identification result

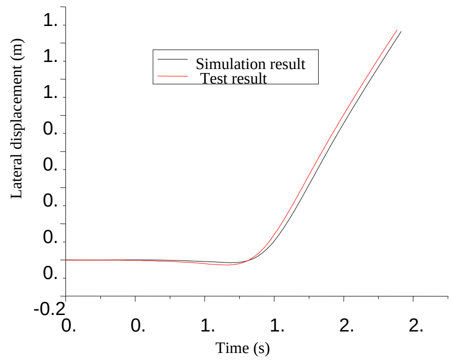


Fig. 9 the comparison of test result and simulation result before compensation

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.

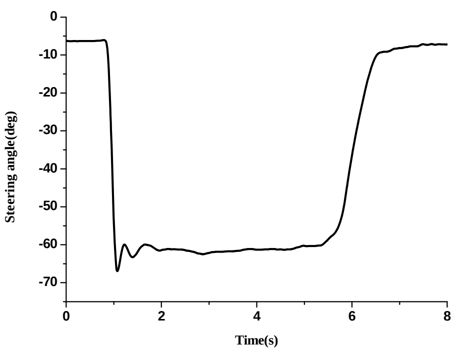


Fig. 7 The step input of steering angle

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.

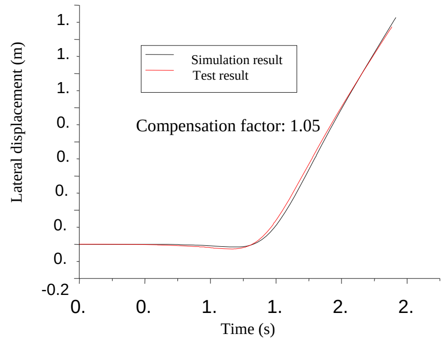


Fig. 10 the comparison of test result and simulation result after compensation

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.

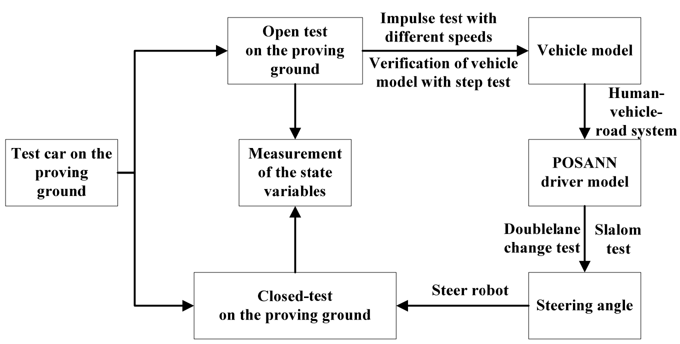


Fig. 11 the measure process of handling stability test

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.

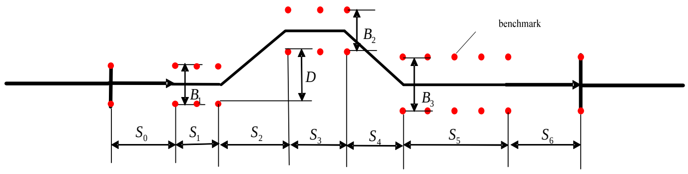


Fig. 12 the site layout of double-lane change test

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

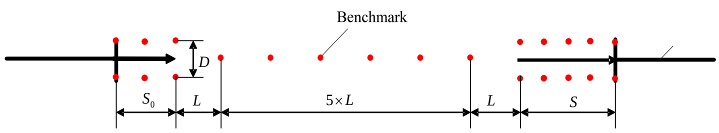


Fig. 13 the site layout of slalom test

$D = 1.1 * bm$, $S_0 = 50m$, $S = 100m$, $L = 30m$, 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.

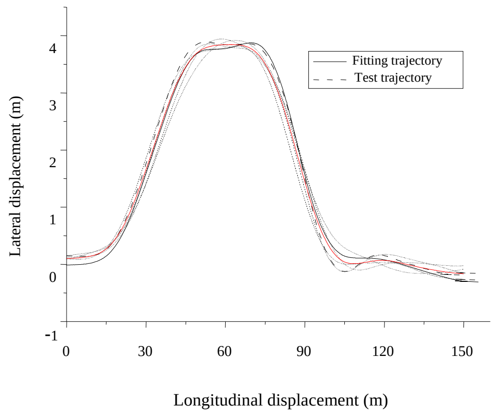


Fig. 14 the fit trajectory and the measured trajectory of double lane change test

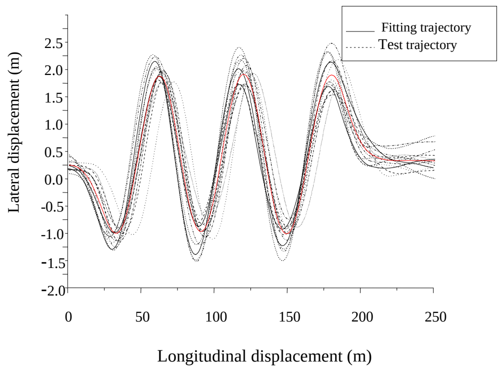
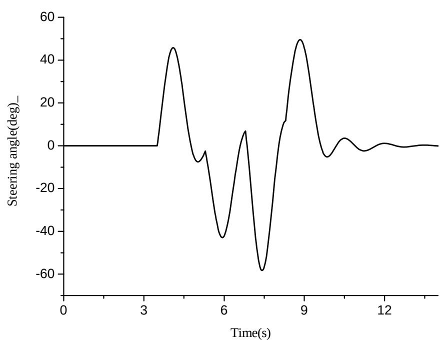


Fig. 15 the fit trajectory and the measured trajectory of slalom test

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.



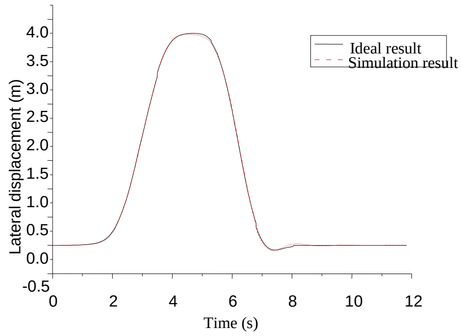


Fig. 16 the steering angle and the lateral displacement of double lane change test

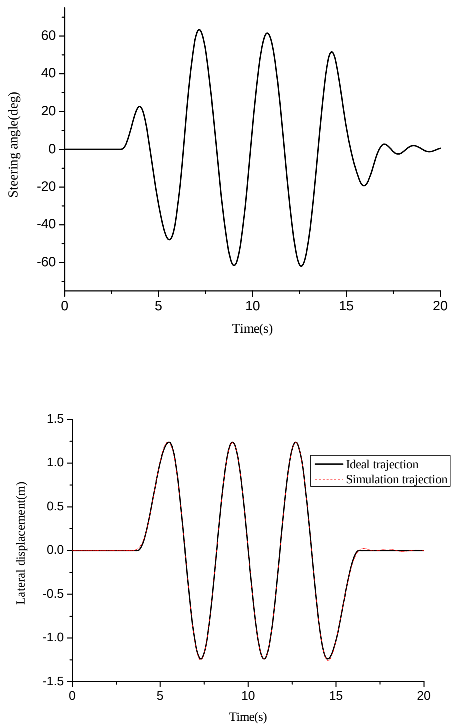


Fig. 17 the steering angle and the lateral displacement of slalom test

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.

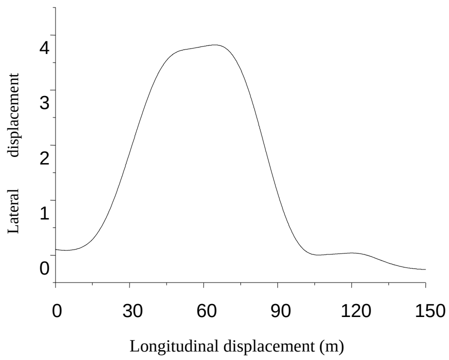


Fig. 18 the trajectory of double lane change test

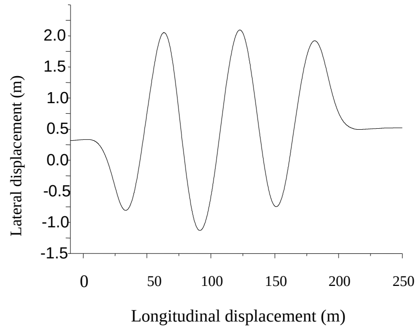


Fig. 19 the trajectory of slalom test

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.

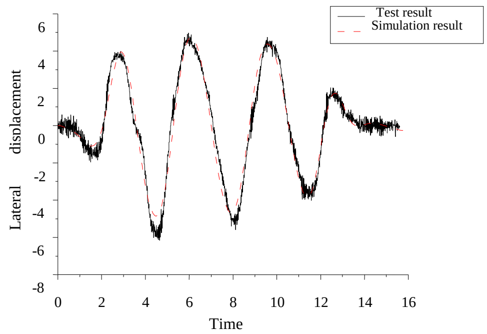


Fig. 20 the lateral displacement comparison of test and simulation

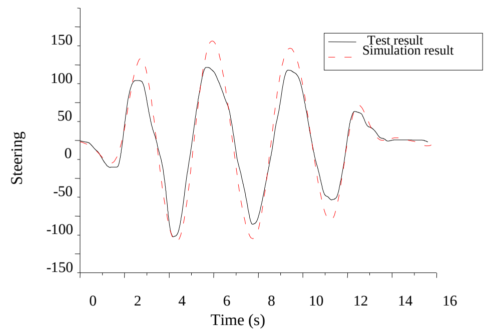


Fig. 21 the steering angle comparison of test and simulation

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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