Research on Testing System for an Intelligent and Connected Vehicle

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Abstract. Due to the increase of automatic driving and network connection function, the testing system of intelligent and connected vehicle (hereinafter referred to as ICV) is quite different from traditional vehicle’s. This paper presents the testing systems of ICV which based on the technology of virtual simulation, semi-physical simulation, and real vehicle test. The testing contents including automatic driving computing platform test, perception system test, network connection and information security test, HMI and ergonomics evaluation, and road test, which covers the automatic driving function, safety, comfort and reliability. The paper introduces the integration architecture and working principles of the testing systems which involves MIL, SIL, HIL, DIL and VIL. The physical relationship of each module in the system is shown by pictures. Finally, the paper summarizes the characteristics and trends of testing system and method. The ICV testing architecture proposed in this paper offers reference for the construction of related laboratories and provide guarantee for ICV application.

1. Introduction

Under the trend of intellectualization and networking, more and more institutions carry out intelligent and connected vehicle (hereinafter referred to as the ICV) research. ICV is integrated with various environment perception sensors to realize automatic driving function by multi-channel information fusion and decision. The key components of ICV include computing platform, cameras, LIDAR, MMW, HMI system, etc. Because of the complexity and novelty of ICV, there is no systematic testing method at present. This paper introduces ICV testing systems and related technologies based on automatic driving and human-machine interface system.

In this paper, the test system and test methods are proposed based on the current ICV integration form, and the test program covers automated driving function, performance, safety, stability, robustness, comfort and interaction. First, the paper proposes a comprehensive testing system and architecture. Then, the test system and method of each part are discussed. Finally, the characteristics of test methods and the development trend are summarized. [1]

2. The architecture of ICV Testing system

The realization of automatic driving function is through three links: environmental perception, route planning and decision, vehicle control. The test system is established based on the technology route, which involves computing platform, sensing system, vehicle high-speed network and HMI system. Classification by tested objects, it is divided into parts, system and vehicle test. For example, Parts and system tests are carrying out to verify the design functions and performance under multiple working
conditions. Road test is a kind of comprehensive vehicle test which focuses on the verification of the automatic driving performance and reliability under traffic scenarios. [2] The technical and testing architecture is as shown in figure1. [2],[3]

![Figure 1. ICV technical and testing architecture](image)

3. Testing content and methods

3.1 Automatic driving computing platform test

For ICV, virtual simulation is a usual method to test the algorithmic logic, robustness, and data processing capabilities of computing platform. There are three test models, including model-in-loop, software-in-loop, and hardware-in-loop testing. [4]

1) MIL and SIL test

Model in the loop (MIL) test can run in the development environment by a series of test cases, such as MATLAB/ Simulink. The purpose of the test is to verify consistency between the model and the design function. It is convenient to find and eliminate errors in the early stage of R & D. Software in the loop (SIL) testing is an equivalence test after MIL which aim to verify consistency between the code and the model, and ensure the deviation is in an acceptable range. Usually we use HIL software to build the test environment and analyse testing results, such as dsPACE and NI.

The MIL and SIL test are a kind of virtual simulation method, and the test system includes workstation, testing software and virtual simulation model. The data interaction between the virtual simulation model and the software under test is realized through the system, which involves road traffic model, vehicle dynamics model, sensor models and the control algorithm. The Mil and SIL test logic are shown in figure 2.

![Figure 2. Mil / SIL test logic](image)
(2) HIL test

Hardware in the loop (HIL) is a kind of semi-physical simulation and which is the most important link of automatic driving computing platform test. It aims to test the comprehensive performance of computing’s software and hardware. The HIL system includes road traffic model, sensor model, vehicle dynamics model, graphic workstation, real-time simulator, and computing platform. The sensor model includes laser point-cloud module, video injection module and MMW module, which is shown in figure 3. HIL test is suitable for complex working conditions with the advantages of high efficiency and repeatability, especially in dangerous scenario and fault injection test. Except for the computing platform of the test system, all links in the rest of the system are simulated by hardware and software. The test system and the logical relationship is shown in figure 3. [5]

![Figure 3. HIL system](image)

3.2 Camera system test

The camera testing system includes camera image quality test and camera system test. The camera image quality test is to verify the physical performance of the camera. In addition, the camera system should be tested in various traffic light environments. There are two types of camera system tests: screen image recognition and video injection. Screen image recognition method is tested by taking screen video with the camera under test, but only adapt to monocular camera. Video injection system transfers data to ECU of camera by bypassing lens, which is suitable for various types of camera tests. The test system integration is shown in figure 4.

![Figure 4. Camera video injection testing system](image)
3.3 MMW radar system test
The MMW radar testing system includes physical performance test and system test. The system test is realized by simulating radar’s obstacle scenario, and the testing scenario is design by defining the speed, distance, angle and equivalent isotropic radiation power (EIRP) of the virtual obstacle. The construction of the complete system should cooperate with the vehicle dynamic model, sensor models, automatic driving computing platform, etc. Figure 5 is the MMW testing system. The HIL system with vehicle and traffic environment models to control the automotive real-Time radar scene generator. [5]

![Figure 5. MMW HIL testing system](image)

3.4 Network connection and information security tests
Network connection and information security tests are significant for L2 and above ICVs. The stronger automatic driving ability of ICV is, the more sensors and ECUs are needed. So, there are higher risk of system being attacked with complex network system. In addition, with the rising permeability of V2X, the more channels the vehicle will be attacked. The testing system can be built based on the real vehicle platform with vehicle network system and CAN bus. The following aspects should be considered in the construction of the test system, as shown in Table 1.

| Test category     | Types of safety evaluation                          |
|-------------------|-----------------------------------------------------|
| Safety design     | Security threat and risk analysis                    |
|                   | Safety design analysis                              |
|                   | Security extension analysis                         |
|                   | Security deployment and feasibility analysis         |
| Safety evaluation | Penetration test                                     |
|                   | Vulnerability scanning                              |
|                   | System fuzzy test                                    |
| Evaluation        | Control system                                      |
|                   | Bus terminal attack                                 |
|                   | Transmission security verification                   |
|                   | Organization structure                              |

3.5 HMI and ergonomics evaluation and test
HMI and ergonomic evaluation include human machine interface, human-machine co-driving, human factors design and automatic driving comfort. In the development stage, static and dynamic driving simulators with cockpit are usually used for test. The system consists of motion platform, cockpit, projector and sound system, human detection equipment (such as eye tracking systems, facial expression analysis system), workstation and cabinet. The intelligent cockpit provides HMI development and testing environment, and the motion platform provides dynamic simulation for the intelligent cockpit. Figure 6 shows the HMI Driver-in-the-Loop Simulation system. [6]
3.6 Road test

Road test is the most widely used test method, which is based on artificial settings or real traffic scenarios. It includes closed road tests and open road tests, and there is a transition test between them called semi-closed road test. In the closed road test, the typical traffic scenes are tested to verify the basic functions of automatic driving. In the open road test, the comprehensive automatic driving ability is tested in the real traffic scene. Generally, open road test can only be carried out after closed road test. The composition of the closed road test system is shown in Table 2.

![Diagram of HMI Driver-in-the-Loop Simulation system](image)

**Figure 6.** HMI Driver-in-the-Loop Simulation system

| Equipment category                        | Equipment content                                      |
|------------------------------------------|-------------------------------------------------------|
| Road environment equipment               | Traffic signs and markings                            |
|                                          | Signal light equipment                                |
| Traffic participant equipment            | Interference vehicle and unmotorized vehicles dummy   |
|                                          | Pedestrian and animal model                           |
| Signal and environment simulation equipment | RSU/LTE-V                                         |
|                                          | WiFi equipment                                       |
|                                          | Information guidance equipment                        |
|                                          | Beidou / GPS and HD map                               |
| Test data collecting equipment           | RT-RANGE                                              |
|                                          | VBOX                                                  |
| Supervisorial establishment              | Camera / Microwave radar                              |
|                                          | Traffic illegal act detection equipment               |
| Driving environment simulation facilities | Weather and road surface simulation facilities        |
|                                          | Road supporting facilities                           |
4. Conclusion

(1) Compared with traditional vehicle test, ICV test is focuses on automatic driving function and performance, network connection and information security, interaction and ergonomic.

(2) The application of virtual simulation technology in test is more and more extensive, which is easy to build complex and dangerous testing environment.

(3) The ICV test involves a lot of fields, and the construction of the testing system shows the coupling of multi-field testing equipment.

(4) The testing system shows the characteristics of combination of virtual and real.

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