Communication and Letters

Verification and Validation of Intelligent Vehicles: Objectives and Efforts From China

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In the last decade, automated driving technology has made remarkable achievements; however, the safety of automated vehicles is not thoroughly guaranteed. Therefore, how to test and improve the safety of automated vehicles has become an increasingly important research topic recently.This article briefly introduces China's current effort on objectives in verification and validation of safety and capability for intelligent vehicles.

I. Introduction

The first noticeable unmanned vehicle challenge held by DARPA in 2004 had attracted ICT companies and Silicon Valley start-ups worldwide to join the research and development of intelligent vehicles, It led to significant changes in the automotive industry. Since 2009, China has also started the annual national Intelligent Vehicle Future Challenge (IVFC) in 2009, initiated at 2009 IEEE Intelligent Vehicles Symposium (IEEE IVS). This series of challenges is sponsored mainly by China's national natural science foundation (NSFC) and is taken as the verification and validation platform for the Key Program on Cognitive Computing for Audio and Visual Perception of NSFC. This series of challenges has initiated and witnessed the rapid development of driverless technology in China for more than a decade, especially the parallel testing technology for autonomous vehicles [1], [13]. Various testing grounds (e.g., IVPC, the Intelligent Vehicles Proving Center in Changsu, China, and M-city in Michigan, USA) have also been built to carry out more comprehensive and detailed tests for automated vehicles [2], [8].

However, there is still a lack of comprehensive and synthetic studies to integrate conventional performance tests of vehicle components, from current functionality tests of vehicles, and future intelligence tests of vehicles. Here, a task refers to an abstract activity that needs to be finished within a period of time. Usually, a vehicle needs to perform several function atoms to accomplish a task successfully [3]. The performance test indicates whether and how a vehicle component fulfills a given detailed specific task. The functionality test indicates whether a special kind of function atoms can be accomplished.

Vehicle manufactories focus on performance tests since human drivers will take care of those hard-driving tasks, including sensing and decision-making. However, automated vehicles themselves, instead of human drivers, should be responsible for fulfilling these hard-driving tasks. As a result, we need to design a set of theories, methodology, and tools to implement all these types of tests.

II. The PTAVC Focus

To reach this goal, we initiated the project "Research on Key Technologies for Performance Test of Autonomous Vehicles and Their Components (PTAVC)," which investigates critical techniques and systems for testing the performance of automated vehicles and their components under complex conditions. PTAVC is supported by the Key-Area Research and Development Program of Guangdong Province, China, which is under the responsibility of China Automotive Technology and Research Center (CATARC), specifically, CATARC Automotive Test Center (Guangzhou) Co., Ltd., which includes 6 project team members: Research Institute of Tsinghua, Pearl River Delta, China CEPREI Laboratory, Guangzhou Automotive Group Co., Ltd., BYD Automobile Industry Ltd., and Waytous (Shenzhen) Inc. The goal is to form a full-process and all-around autonomous vehicle test service chain.

As shown in Fig. 1, we study five topics in this project, including:

1) Theoretical research on autonomous driving performance tests based on the integration of virtual and real testing (or equivalently, parallel testing), aiming to establish the lack of theory;
2) Research on simulation technology and database construction of autonomous drive performance tests, aiming at the problem of time-consuming and long-distance road tests;

Manuscript received April 10, 2022; accepted May 6, 2022. Date of current version July 12, 2022. This work was supported in part by the Key-Area Research and Development Program of Guangdong Province under Grant 2020B0909050003, and in part by the Program of Jiangxi under Grant under Grant 20204ABC03A13.

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Color versions of one or more figures in this article are available at https://doi.org/10.1109/TIV.2022.3179104.

Digital Object Identifier 10.1109/TIV.2022.3179104

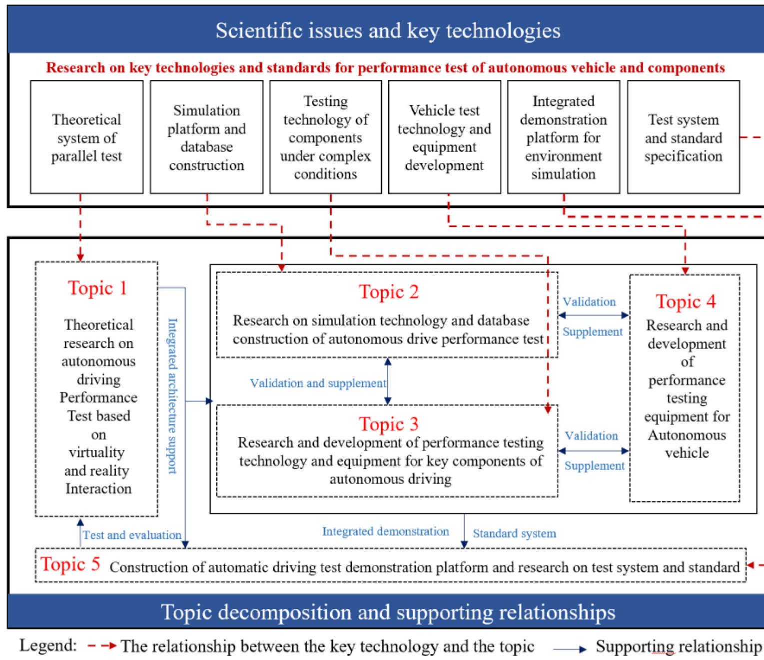

Fig. 1. Overall Structure of the PTAVC Project.

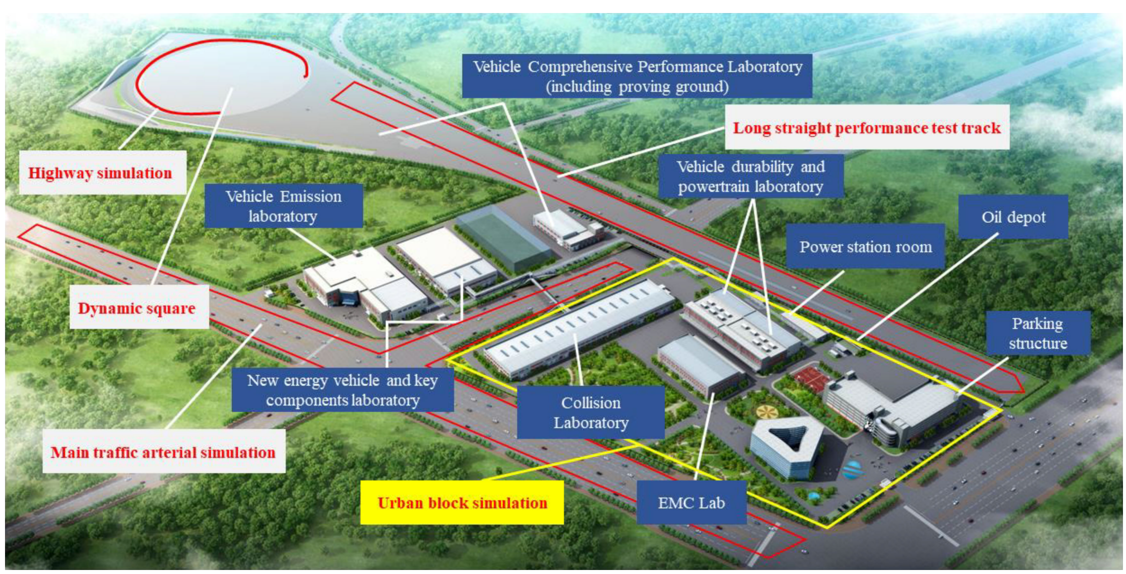

Fig. 2. The PTAVC's Proving Ground at CATARC Automotive Test Center (Guangzhou), including 195000 square meters of road area and 90000 square meters of test laboratories.

3) Research and development of performance testing technology and equipment for key components of autonomous driving, aiming at the lack of performance test system and test equipment for components;
4) Research and development of performance testing equipment for autonomous vehicles, aiming at the problem that the existing equipment of the performance test is inefficient and cannot meet the actual demand;
5) Construction of an automated driving test demonstration platform, and research on the test system and standards, aiming at the problem of lacking pre-access standards for intelligent connected vehicle products.

Fig. 3. Component Test Platforms.

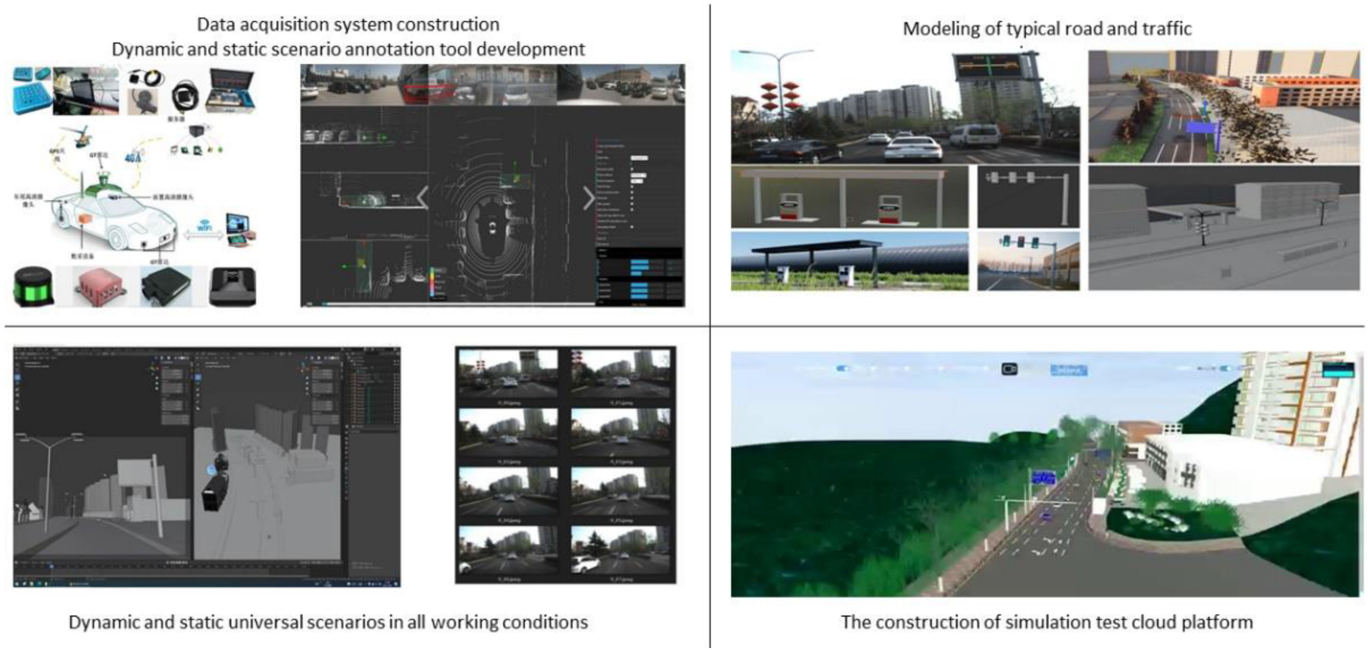

Fig. 4. Construction of the Scenario Database.

The project's main achievements will be demonstrated through the proving ground shown in Fig. 2. The road area of the testing ground is about 195000 square meters, and the building area is approximately 90000 square meters. The high-speed simulation ring is 2876m long. The long straight performance test track is 1400 meters long, and the maximum design speed is 180km/h (suitable for LKA, ACC, AEB, and FCW tests). The diameter of the dynamic square is 300m, which can be used for traditional vehicle dynamics tests and ESP tests. Simulated urban blocks and simulated traffic arterial roads can be used for V2X communication tests and low-speed automatic driving assistance system tests (e.g., BSD and TJA). In addition, the building area is equipped with a comprehensive vehicle test laboratory, an automobile emission test laboratory, a vehicle durability/powertrain test laboratory, an EMC test laboratory, a crash test laboratory, a new vehicle energy laboratory, a power station, and a gas station. These test roads and laboratories can meet all the requirements of testing the whole vehicle and its components.

III. Component Testing and Parallel Evaluation

The basic idea of this project is to integrate field tests and virtual tests executed in cyberspaces [4], [5]. Components will include IMU (Inertial Measurement Unit), GNSS (Global Navigation Satellite System), Lidar, Camera, Radar, and Ultrasonic radar. Sensors affect the performance of the perception systems, which is the fundamental function of autonomous driving systems [6].

As presented in Fig. 3, so far we have built a test platform to carry out performance tests for millimeter-wave radar, camera, lidar, and other equipment. These critical components' reliability, environmental adaptability, and information security must be tested.

All the testing data (including driving conditions, traffic flow, ADAS function test, traffic signs, meteorology, and location) are stored and reused in virtual tests in cyberspace through cloud-edge computing [7]. Virtual tests, as well as simulation-based tests, are investigated and used in this project since the time and financial costs of exhausted field tests are too high to afford. Using virtual tests, we can test whether automated vehicles can successfully pass-through various traffic scenarios and millions of tasks to evaluate the performance of both components and vehicles. We are mainly interested in whole vehicle virtual tests. Compared with the component test, the whole vehicle test often focuses on not a single function, but on a combination of multi-functions since certain problems only appear under some special working conditions of a whole vehicle.

As presented in Fig. 5 and Fig. 6, we build a parallel testing environment [9], [10]. The real field test system is built within a factory whose length is 200m, and the allowed test speed is higher than 100km/h. We can adjust the testing settings (e.g., ambient light intensity, rainfall/ smoke effect) in the real field testing system to simulate various scenarios [12]. It can simulate various environmental factors such as night, sunshine, light rain, moderate rain, heavy rain, dense fog, and slippery road. The system can be used to test navigable soft targets Vehicle (GST), two-wheeled vehicles, and full cars. It can also be applied to test various sensing sensors (e.g., cameras and radars of vehicles) for their imaging perception ability and waterproof capability under ordinary weather conditions.

We build a virtual testing system that can exactly reproduce the real field testing system. This virtual system continues to absorb new real field-testing data to enrich its scenarios and learn the behaviors of all recorded traffic participants. The possible challenging scenarios found by virtual tests will be tested in field tests to check whether the outcomes meet the virtual testing results. The real and virtual systems interact with their digital twin and constantly enhance themselves [11].

To cover as many as possible scenarios that automated vehicles may face, we established a virtual scenario database in this project [8]; see Fig. 4 for an illustration. The most challenging problem of expanding scenario databases is to quickly seek the untested scenarios that might be difficult for the testing vehicles[14]. In this project, we use reinforcement learning, genetic algorithm, and other methods to test and learn which kinds of virtual scenarios might be difficult. Then, we applied the learned models to generate thousands of virtual scenarios

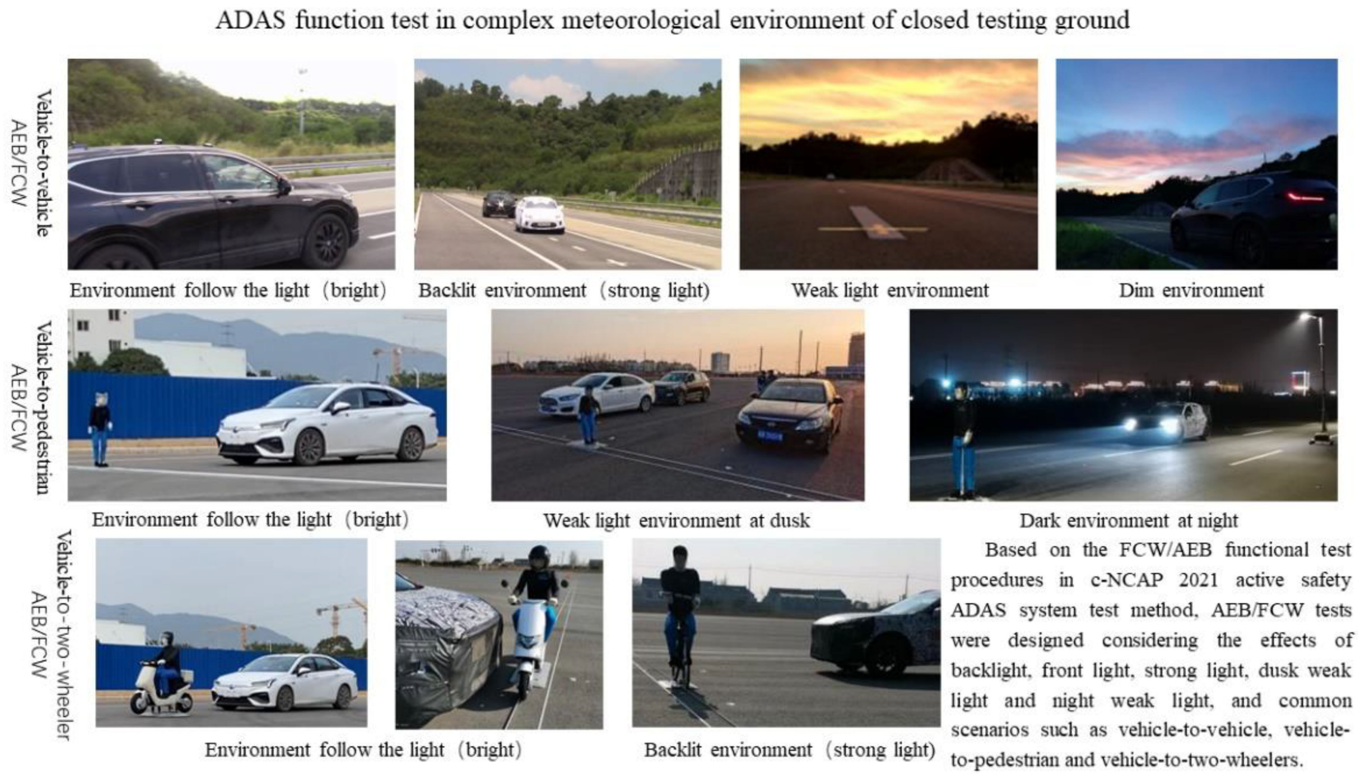

Fig. 5. ADAS Vehicle Test.

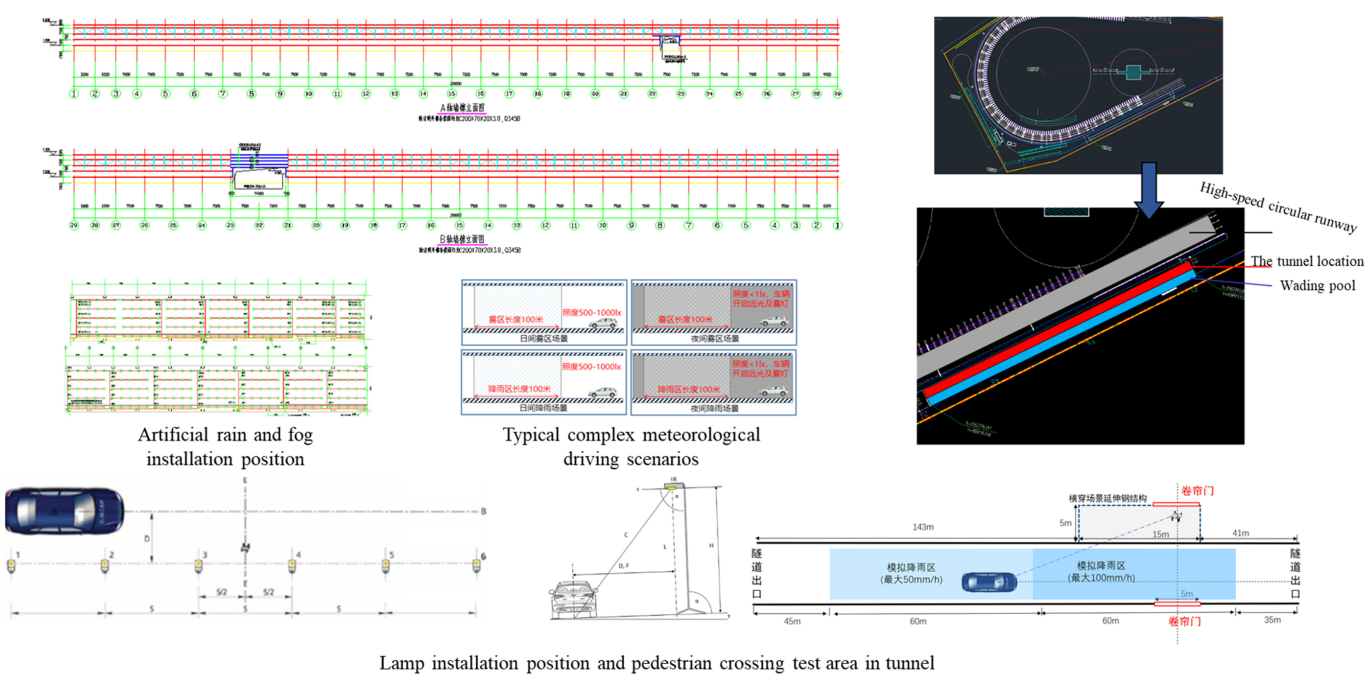

Fig. 6. Environmental Simulation System.

accordingly to enrich the scenario database. Currently, we have more than 5000 test scenarios in the library.

IV. Future Steps

The above summarizes our phased progress in component testing, scenario database generation, and vehicle testing. We will pay more attention to test acceleration and conrner case generation in the future. The effect of parallel testing can be further improved by improving the precision of vehicle testing and improving the component test system. In addition, we will provide a complete set of technical systems and related specifications/standards for autonomous driving performance testing.

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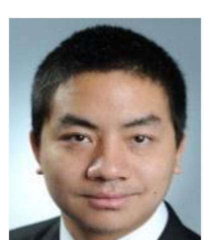

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