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Autonomous-driving vehicle test technology based on virtual reality

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Abstract: In order to mitigate risks from road tests for autonomous-driving vehicles, reduce costs and accelerate development, a virtual reality (VR)-based test platform for autonomous-driving vehicles was built combined with the AirSim system and the UE4 engine by establishing a model library which contains the vehicle dynamics model, sensor models and traffic environment model. The controller-in-the-loop simulation method was implemented to complete the simulation test for autonomous vehicles under different driving conditions and the simulation results were used to optimise the autonomous-driving control system. The actual autonomous driving road test can now be done in an immersive VR simulation environment where autonomous-driving road-testing is done safely and cost-effectively. This plays a significant role in the future development of autonomous-driving vehicles.

1 Introduction

Alongside the rapid development of sensors and radars, machine-vision technology has become increasingly sophisticated [1] and the integration of neural-network algorithms has made autopilot technology a reality [2]. Concerns over the safety of autonomous driving have been the key issues for both the research & development department and the society.

High level of safety is defined as low accident rates in a highly complex system like automobile. It is often costly to solve problems in a new system since there are so many. As the system gets more mature, there are fewer problems left but finding problem solutions becomes more difficult. The current status of autopilot technology is at this stage. The immature autonomous-driving system needs a huge amount of data for optimisation. At the current stage, data mainly come from road tests, which is not only costly but also dangerous. Tests can seldom be repeated under extreme conditions such as collisions, proximity collisions, complex signal intersections and roundabouts [3].

This can now be solved with the virtual reality (VR) technology simulation testing environment we have created. Reconstruct and simulate the real-world road testing in the virtual environment has now been made reality.

VR technology is used to replicate real-world road tests using virtual simulations. The implementation of autonomous-driving vehicle simulation models can reduce cost and improve safety. Cloud computing acceleration technology allows for a 24-h road test for more than a million autonomous cars [4]. This will not only minimise the cost, but also accelerates the development cycle and enable end-to-end deep-learning [5].

At present, this method is used by both domestic and foreign teams to assist the development of autonomous-driving vehicles. Owing to the significance of reducing costs and speeding up development progress, they are gradually becoming the key to the development of autonomous-driving vehicles.

In 2016, Google's Waymo automated driving team developed Carcraft software which was used as an acceleration tool for the development of autonomous driving. The team rebuilt the real world by building physical channels on test vehicles to create digital real-world driving. With the help of Carcraft, three automatic driving test sites (Austin, Mountain View and Phoenix) were rebuilt and >25,000 virtual autonomous-driving car models were released. In 2016, the number of test mileage has reached 4 billion km [6]. In January 2017, the US Department of Transportation designated ten institutions to test autonomous-driving automotive technology. Four of them used a driving simulator as a testing tool [7]. In February 2017, Microsoft has open-sourced the AirSim system for autopilot vehicle testing, which can be used to test the safety of intelligence systems and help researchers and developers use artificial intelligence to build a safer autopilot system in real world [8]. Baidu Apollo's autonomous-driving team set up its own virtual driving platform for autonomous vehicles and implanted it in the Apollo open access platform. The autonomous-driving vehicle virtual simulation engine, which was built based on high-precision mapping technology, was designed to serve the testing and deployment of autonomous-driving systems [9]. In early 2017, RealDrive joined the OpenInnovation project group of BMW and used VR in autonomous-driving training. This enabled them to solve the decision-making errors of autonomous-driving vehicles by means of the road tests and virtual training.

However, the current autonomous-driving simulation work lacks high accuracy in real-world restoration of traffic scene modelling. The existing work only focuses on simulating certain conditions and scenes to obtain experimental data. Whereas, the simulation in a complex and wide-ranging road traffic environment has not been realised. This study introduces a real-world and a highly recovered autonomous-driving vehicle simulation test platform by building a model library, including vehicle dynamics model, sensor models and traffic environment models. It simulates a large-scale and complex transportation network using traffic environment intelligent simulation technology and uniting the AirSim system and UE4 engine. Based on the simulation test platform, the HITL simulation method of the controller-in-the-loop was implemented to complete the simulation test of the autopilot vehicle under various working conditions. The simulation results were used to optimise the autopilot vehicle control system and the method of replacing the road test with autonomous-driving simulation test in a virtual environment was initially realised.

2 Architectural overview

As shown in Fig. 1, a dynamic vehicle model, sensor models and traffic environment models are constructed through virtual modelling to restore the autonomous-driving vehicle in a virtual environment. The simulation model contains the core part of an

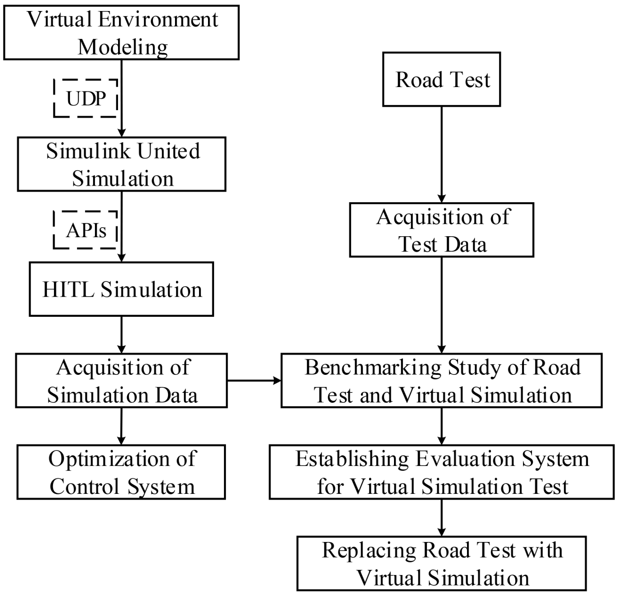


Fig. 1 *Virtual environment autonomous-driving simulation*

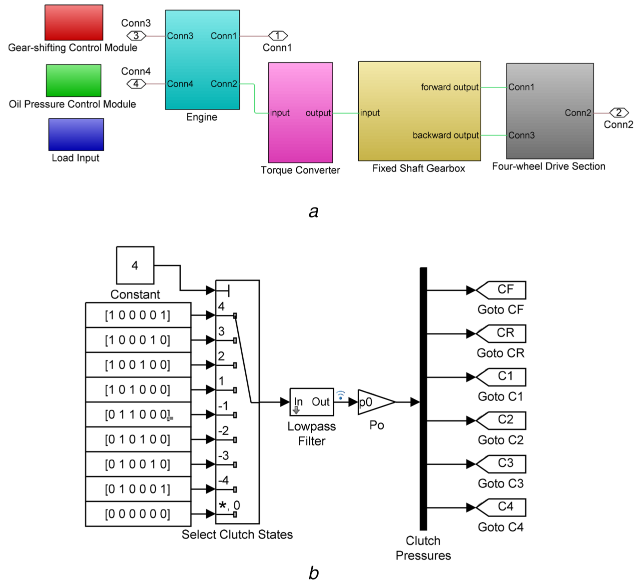


Fig. 2 *Dynamics model based on a certain type of car*
(a) Vehicle dynamics model, ***(b)*** Gear-shifting control module

autonomous-driving vehicle and the decision making of the system can be simulated by setting different working conditions. A user data protocol was established to realise the communication between the simulation system and the Simulink vehicle dynamics simulation module. The data calculated by the dynamic simulation module will be transmitted to the simulation system to control the estimated status of the vehicle. The controller of the autonomous-driving vehicle is connected by using the simulation system API to implement HITL simulation. The data collected from the simulation was used to optimise the autonomous-driving system and then the system will be tested, optimised and the process repeated again. On the other hand, an evaluation index and optimisation method for the autonomous-driving vehicle test in the virtual environment were established using the data collected from the road test and the virtual simulation via benchmarking. Finally, the virtual simulation can replace road test.

The full-vehicle dynamic model based on a certain type of cars was built in Simulink with modular design for the purpose of easy integration. The vehicle dynamics model built in Simulink is shown in Figs. 2*a* and *b* which is the model of gear-shifting control module.

3 Traffic environment intelligent generation

How to make the virtual scene as realistic as possible is the most common question for testers in simulation testing. However, the cost to reproduce a few kilometres real road in the virtual environment using traditional manual methods is extremely huge, not to mention the cost of building a network of urban roads. Intelligent generation for traffic environment based on high-precision maps can solve the ineffectiveness of traditional manual modelling.

OpenDRIVE is an open format specification describing road-network logic [10]. It has a wide range of applications in the virtual driving testing. As shown in Fig. 3, traffic environment intelligent generation can generate structured road and unstructured road traffic environments spontaneously. With the help of high-precision map technology, the rendering system can directly import and read standard OpenDRIVE files and retrieve road structure data from OpenDRIVE. Information extracted from previously established mapping relations (as shown in Table 1), can be retrieved from the road element database corresponding to the model file (such as road geometry, intersections, lane lines, traffic signs etc.). It is rewritten into the map files in the resource library and is used by the rendering engine for reading and rendering in order to create an actual traffic environment. To achieve the purpose, we use a render plugins developed with C++ based on the UE4 engine. In this way, diversified traffic environments can be easily restored by establishing a virtual environment model library. By implementing the environmental intelligence generating algorithms, traffic environment that has already established in the database is automatically selected and combined in accordance with reasonable rules and traffic conditions in reality. Following this, a large-scale urban traffic network is reproduced in the virtual environment and serves a significant role in our simulation platform.

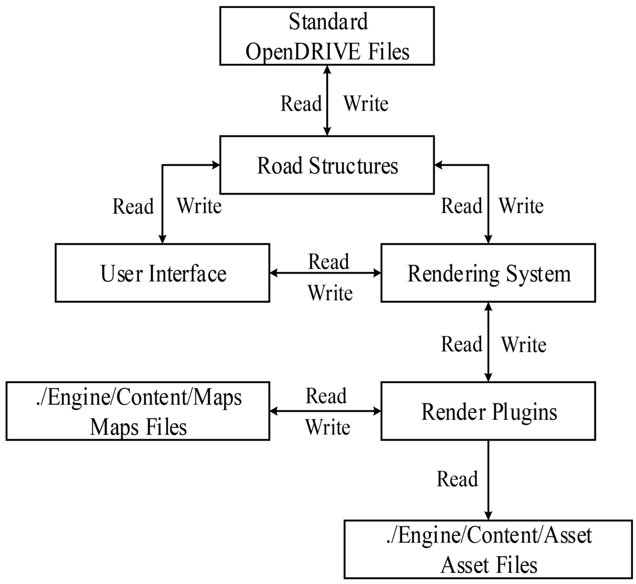


Fig. 3 *Traffic environment intelligent generation*

4 Autonomous-driving vehicle test platform in the virtual environment

AirSim is an open source platform based on C++ language developed by Microsoft Corporation. It aims to narrow the gap between simulation and reality in order to facilitate the development of autonomous-driving vehicles [11].

Through the modelling of simulation models such as traffic environment models, sensor models and vehicle dynamics models, based on the AirSim system, using the UE4 high-precision rendering engine [12], the multi-functional virtual environment autonomous-driving vehicle simulation test platform, shown in Fig. 4, is established which provides testing, development and optimisation functions for autonomous-driving vehicles.

Table 1 Mapping relationships between some OpenDRIVE road structure data and road element database models

	OpenDRIVE data	Road element data
road geometry	reference line	road_geometry.uasset
traffic sign	features	road_feature.uasset
lane line	lanes	road_lane.uasset
intersection	• successor/predecessor linkage • junctions	road_intersection.uasset

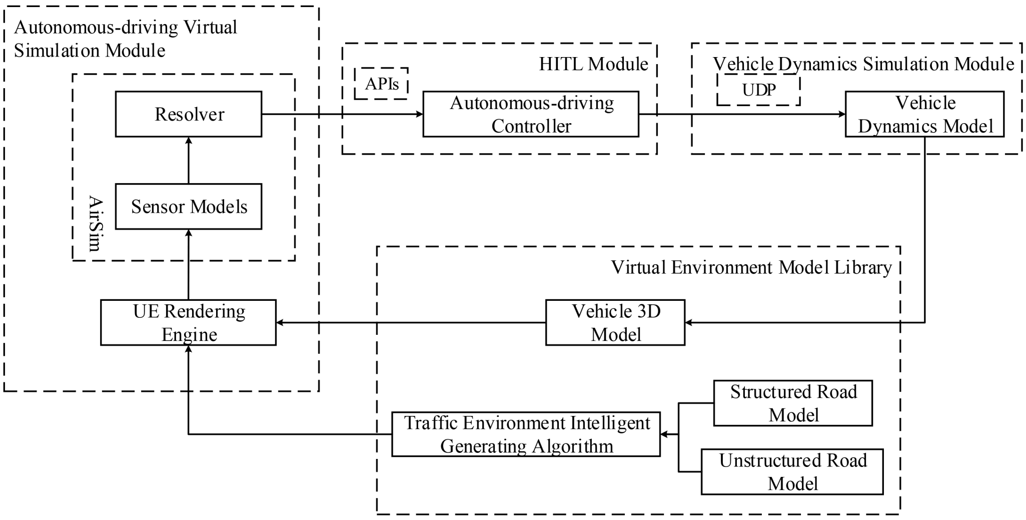
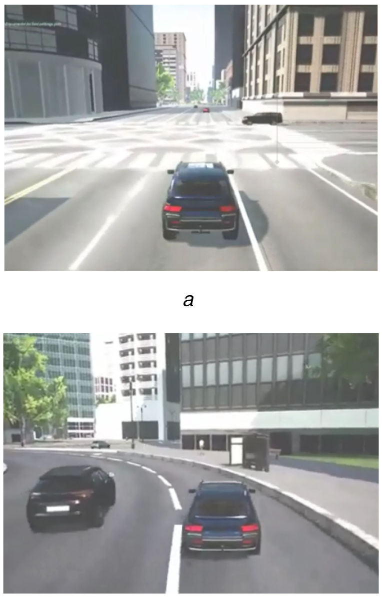


Fig. 4 *Autonomous-driving test platform in virtual environment*



a

b

Fig. 5 *Various tasks in the urban roads test on structured road*
(a) Passing crossing, ***(b)*** Passing roundabout

The design of the platform follows modular design which emphasises scalability. The platform is constructed with the autonomous-driving virtual simulation module, the vehicle dynamics simulation module and a virtual environment model library. The main part of the core components includes the traffic environment model, vehicle dynamics model, UE rendering engine, sensor models, rendering interface, public API layer and interface layer for vehicle HITL simulation. In the process of simulation, the simulation system provides sensor data obtained from the virtual environment and transmits it to the autonomous-driving controller that accesses the simulation system. The autonomous-driving controller receives the expected driving status and sensor data as input. It then calculates the estimated current status and control signal to adjust the driving state of the vehicle model in the simulation system. Subsequently, there will be a loop which unites the hardware and the simulation model. In this process, causing it is a HITL simulation, the frequency synchronisation should be strictly guaranteed.

With the aid of the virtual simulation platform, tests of autonomous-driving vehicles are conducted on both structured and unstructured road environments. Tests are conducted to test how the autonomous cars complete the tasks on urban pathways. As shown in Fig. 5, main tasks include: autonomously passing crossings, avoiding pedestrians, overtaking, setting parking positions, overpasses etc. Following this, we tested the performance of auto-driving vehicles in terms of environmental awareness, path planning, high-precision positioning and autonomous decision-making.

Fig. 6 is a snapshot from AirSim showing an autonomous car driving in the VR setting. The three monitoring windows inserted show the depth information, object segmentation information generated by the sensor model in real time and the images captured by the front camera, respectively.

5 Conclusion and future work

This study sets up vehicle dynamics models, sensor models and traffic environment models, combines with the AirSim system and UE4 rendering engine, builds a test platform for autonomous driving vehicles under virtual environments and adopts the controller-in-loop HITL method to complete the autonomous-driving vehicle simulation test under a variety of operating conditions. Compared with the existing automatic driving simulation technology, this system uses a road network that is variable, complex and wide-ranging. It is characterised by randomness and long test mileage. It realises the road test of autonomous-driving vehicles recurring in the virtual environment and will play an important role in the development of autonomous-driving vehicles.

The results will inevitably be inaccurate since the virtual simulation test is based on the sensor model and the computer physics engine. Through the experimental results, the sensor model and the vehicle dynamics model are modified to establish more scientific virtual simulation test evaluation standards. It is of great importance for autonomous vehicles under virtual simulation

a

b

Fig. 6 *Snapshot from AirSim shows an autonomous-driving vehicle driving in the virtual environment*
(a) Test on structured road, ***(b)*** Test on unstructured road

testing. We believe that with the maturity of this technology, the development of autonomous-driving technology will enter upon a new stage.

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