Scenario-Based Virtual Testing for Autonomous Vehicles: Methods and Considerations

Huijia Sun*
Shanghaitech University
Shanghai, China
sunhj2022@shanghaitech.edu.cn

Hongchen Cao*
Shanghaitech University
Shanghai, China
caohch1@shanghaitech.edu.cn

ABSTRACT

In recent years, Autonomous Vehicles (AVs) have attracted attention because of their significant potential to save fuel, reduce crashes, ease traffic congestion, and provide better mobility. In the development and deployment of AVs, testing AVs' driving intelligence is definitely a critical step. Overall, the expensive, inefficient and dangerous real-world testing can be replaced by virtual testing that makes it possible to test AVs from different aspects. But it can be time-consuming because of the rarity of dangerous events. As a result, generating critical scenario-based test cases for virtual AV testing becomes a common attempt. There have been many works offering various approaches to settle the issue so far. In this survey project, we aim to discuss a set of existing works to summarize the progress and basic considerations in the field of scenario-based AV testing.

CCS CONCEPTS

• **General and reference** → **Surveys and overviews**.

KEYWORDS

autonomous vehicle testing, autonomous driving safety, safety-critical applications

1 INTRODUCTION

Autonomous Vehicles (AVs) are under rapid development recently and increasingly becoming an integral part of our daily life, with many new and established companies actively developing AVs [1]. It is no doubt that there are many profound benefits that could arise from a driverless future. With some companies, e.g., Baidu, already bringing truly AVs to market [2], a driverless future seems just around the corner, whereas it's been a long arduous journey to arrive at this point. One of the key issues is AV safety and security.

1.1 Motivation

During recent years, AVs with low-level autonomy has resulted in a set of fatalities [3–6]. Hence, considering the safety-criticality of such vehicles and the fatality of any minimal error in AVs, extensive testing is required during AVs' development. However, since real-world testing is expensive, inefficient, and dangerous, a common practice is virtual testing, which makes it possible to test AVs from different aspects [7].

*Both authors contributed equally to this research.

1.2 Research Problem

One of the major challenges is obtaining scenarios that are critical enough to be used as test cases. Virtual testing can be time-consuming because of the rarity of dangerous events [8]. Overall, it is necessary to get more critical test cases for effective and efficient virtual testing. A reasonable practice is generating critical scenarios for virtual testing automatically.

AV testing is also challenged by the oracle problem. An oracle is a mechanism that testers use to determine whether the outcomes of test case executions are correct. The oracle problem is a situation where an oracle is unavailable or is too expensive to be applied. For the testing of autonomous vehicles, it is hard to construct a fully automated test oracle. For example, in a complex road network, it is hard for the tester to decide whether the driving route selected by the autonomous car is optimal.

1.3 Contributions

In our survey project, we will make the following main contribution:

- Offer an overview of some research into scenario-based virtual AV testing;
- Consolidate and distill the progress in the field of scenario-based virtual AV testing.

2 METHODOLOGY

The research focuses on a systematic keyword search in the topic section of literature databases, including ACM Digital Library [9], IEEE Xplore Digital Library[10], and Springer Lecture Notes in Computer Science[11]. The search conducted included the specific terms, "Autonomous driving testing", "Self-driving car testing", "Autonomous vehicles testing", "Driverless car testing", "crash avoidance", "advanced driver assistance system", "automated vehicles testing", and "intelligence testing" either in the title, keywords or abstract and included only academic journals and conferences listed in the mentioned databases. As mentioned in Sec. 1.1, we do not aim to investigate all papers related to autonomous driving safety testing, it is too large and we focus on scenario-based virtual testing. Therefore, we further filter papers related to this topic. Constrained by time and effort, we will choose 8 high-quality papers that have a strong inter-relationship with each other for the final study, thus summarising the progress and basic considerations in the field of scenario-based AV testing.

As stated above, the ADS is systematically evaluated against a number of different scenarios and oracles.

Scenarios are configurations of objects on a map (e.g. obstacles, pedestrians, and vehicles) as well as their dynamic behavior [12]. There are four prevailing categories of approaches for obtaining scenarios in AV testing. The first approach is to identify the most

challenging scenarios using model-based optimization techniques [13, 14]. The second one is to build stochastic models based on the big data obtained from the real-world driving environment to represent human driving behaviors and to run Monte Carlo simulations to evaluate AVs [15, 16]. Domain-specific languages (DSLs) are used to describe test scenarios in the third approach, and the last one fuzz testing technique[17, 18].

Oracles in AV testing are criteria by which the AV's driving intelligence is evaluated under every test scenario. Most existing testing frameworks still tend to use weak oracles such as 'non-collision'. However, LawBreaker [19] subtly evaluates AVs on their ability to complete a journey without both causing collisions and violating traffic laws. Besides, the comfort of driving also needs to be considered because it is clear that having too much lateral acceleration in a journey is undesirable.

REFERENCES

[1] August 2019. 46 Corporations Working On Autonomous Vehicles. https://www.cbinsights.com/research/autonomous-driverless-vehicles-corporations-list/.

[2] August 2019. Baidu starts mass production of autonomous buses. https://www.dw.com/en/baidu-starts-mass-production-of-autonomous-buses/a-44525629.

[3] August 2019. Self-Driving Tesla Was Involved in Fatal Crash, U.S. Says. https://www.nytimes.com/2016/07/01/business/self-driving-tesla-fatal-crash-investigation.html.

[4] August 2019. Self-Driving Uber Car Kills Pedestrian in Arizona, Where Robots Roam. https://www.nytimes.com/2018/03/19/technology/uber-driverless-fatality.html.

[5] August 2019. Tesla: Autopilot was on during deadly Mountain View crash. https://www.mercurynews.com/2018/03/30/tesla-autopilot-was-on-during-deadly-mountain-view-crash/.

[6] August 2019. Fatal Tesla Crash Exposes Gap In Automaker's Use Of Car Data. https://www.forbes.com/sites/alanohnsman/2018/04/16/tesla-autopilot-fatal-crash-waze-hazard-alerts/#7bb735fb5572.

[7] M. R. Zofka, S. Klemm, F. Kuhnt, T. Schamm, and J. M. Zollner, "Testing and validating high level components for automated driving: Simulation framework for traffic scenarios," in Proc. of the IEEE Intelligent Vehicles Symposium, 2016.

[8] Kalra, N. and S. M. Paddock. Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability? Transportation Research Part A: Policy and Practice, 2016.

[9] Association for Computing Machinery. The ACM Digital Library. https://dl.acm.org/

[10] Institute of Electrical and Electronics Engineers. IEEE Xplore Digital Library. https://ieeexplore.ieee.org/Xplore/home.jsp

[11] Springer Nature. Springer Lecture Notes in Computer Science. https://link.springer.com/search?facet-discipline="Computer+Science"

[12] T. Menzel, G. Bagschik and M. Maurer, "Scenarios for Development, Test and Validation of Automated Vehicles," 2018 IEEE Intelligent Vehicles Symposium (IV), 2018, pp. 1821-1827, doi: 10.1109/IVS.2018.8500406.

[13] Althoff, M. , and S. Lutz . "Automatic Generation of Safety-Critical Test Scenarios for Collision Avoidance of Road Vehicles." 2018 IEEE Intelligent Vehicles Symposium (IV) IEEE, 2018.

[14] Klischat, M. , and M. Althoff . "Generating Critical Test Scenarios for Automated Vehicles with Evolutionary Algorithms." 2019 IEEE Intelligent Vehicles Symposium (IV) IEEE, 2019.

[15] Zhao, D. , et al. "Accelerated Evaluation of Automated Vehicles Safety in Lane-Change Scenarios Based on Importance Sampling Techniques." IEEE Trans Intell Transp Syst (2017):1-13.

[16] Feng, Shuo , et al. "Intelligent driving intelligence test for autonomous vehicles with naturalistic and adversarial environment." Nature Communications, 2021.

[17] Li, G. , et al. "AV-FUZZER: Finding Safety Violations in Autonomous Driving Systems." 2020 IEEE 31st International Symposium on Software Reliability Engineering (ISSRE) IEEE, 2020.

[18] Wan, Z. , et al. "Too Afraid to Drive: Systematic Discovery of Semantic DoS Vulnerability in Autonomous Driving Planning under Physical-World Attacks." 2022.

[19] Yang Sun, Christopher M. Poskitt, Jun Sun, Yuqi Chen, and Zijiang Yang. 2022. LawBreaker: An Approach for Specifying Traffic Laws and Fuzzing Autonomous Vehicles. In 37th IEEE/ACM International Conference on Automated Software Engineering (ASE '22), October 10–14, 2022, Rochester, MI, USA. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3551349.3556897