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Intelligent Driving System effectiveness testing in Highly Automated Vehicles

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Abstract

The autonomous vehicles will appear on the road as soon as possible in the future. But first, the developers need to think about the highly automated vehicles and conventional vehicles. Because they may conflict with each other during transport, that is why required to use various safety, and security features in environment sensing become increasingly important. These automated functions support the drivers and replace them in specific movements. For the safe ride, the vehicles need to recognize the environment very accurately. The automotive industry can make an environment sensing system safely with a design test scenario in many types of critical tests. There are some advantages and disadvantages of autonomous test types, but it is always useful. This paper demonstrates our test scenario (which is on the ZalaZONE proving ground in Hungary) with three kinds of highly automated vehicles, focus on driver assistance applications such as traffic sign recognition. We provide in this article some examples of the extreme factors, considerations, and roadside anomalies that require testing and validation of sensor systems.

Keywords: traffic signs anomalies, highly automated conflicts, environment recognition

1 Introduction

Currently, developments are made to autonomous vehicles all over the world. With the advent of new comfort and safety features, the vehicle industry is continually evolving. The primary goals of autonomous vehicles are to reduce environmental pollution, emissions, and the number of accidents. Automated vehicle functions execute a significant role in reducing these factors and are more effective than human drivers. Further benefits can be achieved by improving infrastructure and connecting vehicles, such as reducing traffic and travel time. But maybe in the future, the infrastructure, traffic signals, traffic rules need to develop in parallel with the autonomous vehicles.[1]

Advanced systems provide more efficient and safer transport than human drivers. Vehicles can be graded from 0 to 5 according to SAE (Society of Automotive Engineers) levels. [3] The first of which means that the vehicle has no degree of automation. The fifth level is characterized by the fact that the vehicles are capable of driving on their own. And as the tools in the levels evolve, for example, the autonomous levels increase, and functions expand, there is a need for layer control as a redundant system. The autonomous vehicles need to know about their environment and control the vehicle in safety, such as trajectory planning and following. [4]

In technologies, there may be a problem between the necessary laws. In the case of autonomous vehicles, there are legal issues besides design tests. Therefore, essential to building a single decisionmaking system between countries that applies to autonomous vehicles. Some aspects are summarized in the current statement in the Vienna Convention on Road Traffic, which must clearly state that a vehicle should always drive by a human driver. The other difficulty is to decide responsibility. For example, if an accident occurs in an autonomous mode, then who is responsible. There are, of course, suggestions on how they can be grouped and likely to continue to develop. [5]

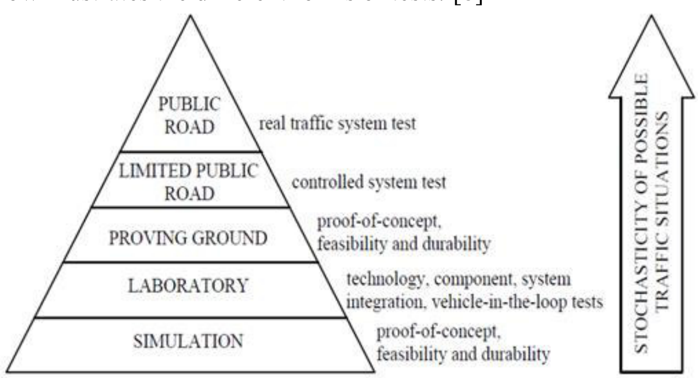
Because of new technologies and functions, it is essential to create further testing and validation methods. [6] The sensors and other systems in the vehicles should all know what people recognize and do with their senses in many situations.

With the advantages of existing testing methods, it is possible to test autonomous vehicles in critical circumstances or failure modes. But the real environmental testing is hard in actual traffic conditions. All these tests are hard reproducible, always need a method with a ruleset. This paper examines the existing techniques of autonomous driving functional testing, verification, and validation. This knowledge is useful for our processes and helpful to set up some reliable, quick, safe, low cost and reproducible testing methods and accelerate the development.

2 The methodology of test and validation

Today, modern vehicles are made up of several subsystems, most of which contain age-appropriate electronic components, such as embedded systems that perform the function of regulation, actuators that physically operate various components, or sophisticated, high-sensitivity, long-range sensors. Due to a large number of subsystems and the number of products produced annually by vehicle manufacturers and their suppliers, it is no longer possible in engineering practice to test early-stage versions of subsystems and their components in the final product. Samples can also be examined under conditions that best approximate reality. As a result, various simulation procedures have become an indispensable element of product development, which can be applied with excellent efficiency with the advent of increasingly powerful computers and the creation of increasingly realistic simulation algorithms. The purpose of using simulations is to observe the behaviour of different systems and, in most cases, to test them in vehicle development, which has the additional positive effect of accelerating development processes and reducing costs by eliminating errors at an early stage of development.[7]

Several types of tests can be distinguished. Some initial tests, such as those in a simulation environment, are cheaper, safer, and faster, and are easier to adapt in the real world. On **Hiba! A hivatkozási forrás nem található.**. test and validation pyramid can help validate a system; the pyramid shown below illustrates the different forms of tests. [8]



1. Figure Test and validation pyramid [8]

2.1 Simulation testing

The role of simulation procedures used in vehicle development can be grouped in several ways, depending on whether we consider simulation as a tool for product development or testing, or as a tool that makes the whole development process faster and more economical. In the following, I examine the simulations from these two perspectives.

Economic benefits of using simulations during product development, it is essential to filter out possible errors at the earliest possible stage and to identify not only the mistakes of the given product but also the cooperation and communication errors with other tools during its later integration. That is why it is necessary because the repair costs due to each defect increase significantly in the various product development phases from concept to series production. [9]

One possible way to eliminate defects is to use simulations, which can be used to test and even validate products in different stages of development until they need to be installed in a specific vehicle.

First, simulation is well-defined mathematical modelling that can give very close results to the real world. [10] It is the most typical advantage understanding of the functioning of systems by modelling reality. "Key Elements of Computer Simulation:

- Integrated vehicle dynamic simulation,
- Combined traffic and traffic simulation,
- Interaction simulation with other transporters
- Simulation of visibility and weather
- Simulation of region-specific road conditions and traffic signals. "

The simulation test environment is the basis for the rest of the tests. There are two ways to apply it. It is primarily listed as a Level 1 test in the test and approved list. Secondly, it can be a test track and road test scenario. Some of the errors that occur during tests can be eliminated using the simulation environment, making them much more economical.

Critical elements of computer simulation include integrated vehicle dynamics simulation, traffic and traffic simulation, interaction simulation with other transport actors, visibility and weather simulation, and simulation of region-specific road conditions and traffic signals.

More and more software is developed to test the various autonomous functions in advance. Examples include Vires, IPG Carmaker, and PreScan. In this case, we present the advantages and disadvantages through PreScan.[13]

PreScan is a software developed by TASS International that provides a development environment for management support systems. The program consists of several main modules. The simulation engine of PreScan is SimCore, which controls the sensor simulation, visualization environment, and combined dynamic and control functions. [11]

There are many benefits to using a simulation environment for testing and developing autonomous vehicles and their features. In any case, it is worth taking advantage of the help of the software to make or repair a sensor. It is advantageous if you want to design a test scenario or quickly modify an existing one. By running a preliminary simulation of the tests, they can quickly identify potential errors and can be easily and economically repaired at this stage. The use of "vehicle in the loop" for future real tests is a significant economic and security advantage for testers and developers. Despite the disadvantages of using simulation software, which can be easily eliminated by improvements, it is entirely usable and supported in the development of autonomous vehicles. That is why we create first the test scenario in simulation software. [22][23]

In the future, the further development of the Neural Network with detection capability can help to prepare the scenarios. Then, after completing the simulation environment, the next step, the real tests on the ZalaZONE proving ground.

2.2 Laboratory testing

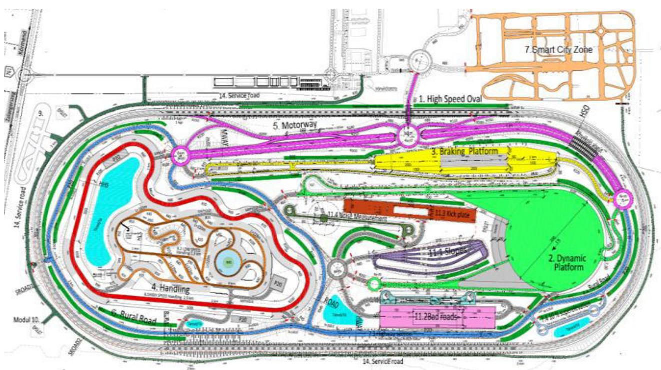
The next phase is the implementation of the laboratory tests, which will enable the vehicle-in-the-loop (6), the existing systems separately or even the entire system. It is possible to perform tests in a closed environment several times on test tracks, which provides a safe test for testing improvements. [14] The autonomous vehicles need automation functional test on source code level security of enduringly safety-critical systems. The testing practices could be used, which requires automatically created test cases, hardware-in-the-loop (HIL) testing use ISO26262 functional safety specifications. [12][26]

The other options between the laboratory and real test environment are the Software-in-the-loop (SIL) simulations, where the remaining hardware components, vehicle dynamics, and environment are simulated in real-time. [7]

2.3 Proving ground testing

There are several test tracks available worldwide for developers to test traditional systems. In recent years, they have begun to build the types of trails that can be used by highly automated and autonomous vehicles to test all functions.[8]

The primary purpose of the sensors is to detect movements in the environment and collect information about it. Following the appropriate inputs, use the command layer to instruct the vehicle to plan the route. Environmental sensors are sensitive to environmental influences, so more attention should be paid to their testing. The following examples, experiments, highlight the need to address their weaknesses and then tailor the tests to the end so that the developer can get a complete, secure system.



2. Figure Proving Ground in Zalaegerszeg [24]

3. Figure Comparison of simulation and real test

Cameras can already be tested in the simulation process with several factors. The software has been developed to test various driver assistance systems. The Traffic Signal Recognition System is an excellent example of how sensitive a camera-based recognition technique is. Figure 3 shows a measurement prepared in a simulation program that is completed on the ZalaZONE Smart city test track in March 2019. The software offers a lot of possibilities for distorting the boards (mud, scratches, snow), [11] making the position of the recognition systems more difficult. There is a significant difference in the appearance of the environments (simulation, real), which may distort the measurement results. Based on the examples mentioned above, preparation and design is an essential step in the development of a new function in the simulation process. It proves that the need for tests in real-world environments too. Finding the perfect test method need to test in a lot of various situations with many types of vehicles. [15][16]

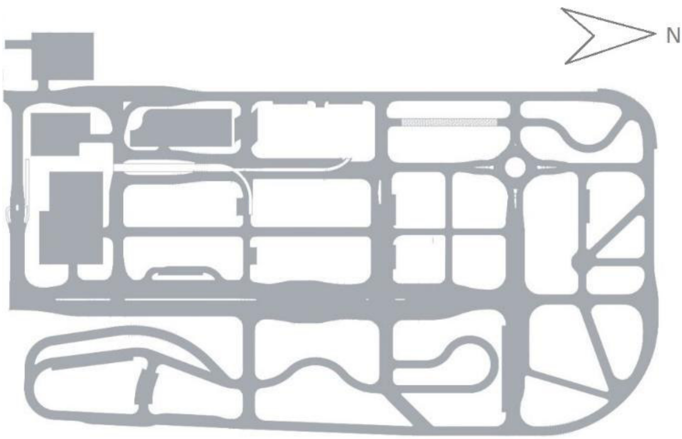
4. Figure Location of the measurements at Zcity

2.4 The location of the test

The measurement started in autumn at 10:00 and lasted until 16:00. From the results, we had to pay attention to the light conditions and the sun. It was deliberately selected to measure the day, so the most critical condition could be examined for recognition. For the scenario planning we used the test and validation pyramid steps. [25]That's why, first we chose our test location (implemented Smart City) in simulation software; after that, we used photos about ZalaZONE and planned the real environment scenarios. (Figure 4, 5, 6.)

5. Figure Recording the measurement

The speed limit on the vehicles were 20-25 km/h. We recorded the measurement with two GoPro cameras and mobile phones with different angles of view. The traffic signs were used in the measurement was selected according to the standard (2.2 m). We used some traffic signs which were the ZCity included and also we had some speed limit 30 km/h signs. [17]



6. Figure Our chosen test area on ZCity at ZalaZONE

2.5 Traffic signs anomalies of the test

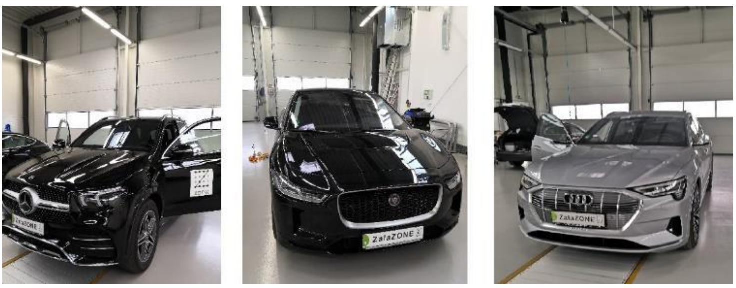
We use some parameters that are included in the measurement table. The traffic sign anomalies were chosen by previous measurement experience. The visibility means when a traffic sign cover by a tree or column: the clarity when you can see a clear traffic sign, or a foul one. Recognizability is when you watch a traffic sign size, deformity, colours, and stickers. [18] The position means that the sign is not at the right height. Simplicity means when too much or conflicting information should be observed. [19] This table which include an example with traffic signs anomalies help us previously measurements and tests.

Table 1. Classification of traffic sign anomalies

	Visibility 1= not visible 5= visible	Clarity 1= dirty 5= clear	Recognizability 1= not recognizable 5= recognizable	Position 1= Improper 5= standard	Simplicity 1= complex 5= simply
1. Example	1	4	2	2	4

2.6 Vehicles of the test

We got an opportunity in last year from the JRC (Joint Research Center), we could choose three types of highly automated vehicles. We thought about which vehicle for the best for our measurement and chose an Audi e-Tron, Jaguar I-Pace, Mercedes EQC 400. All of these vehicles are electronic but include the modernist traffic sign recognition system. (Figure 6.) [10]



7. Figure Test vehicles on ZalaZONE

2.7 Some remark of the test

We needed to plan the test trajectory for the safe and short test time; that’s why we chose a circle on the test track. But we needed to think about how we cancelled the recognized traffic sign about the test vehicle. It was interesting for us that we need another type of traffic sign for the cancelling.

For the experience of previous tests, we needed to think about the reproduction. We chose the traffic sign with Speed Limit 30 km/h (because it’ was easy to get them), we took them in one line, and we rotated just one traffic sign with one anomaly. (Figure 7.) This was a good opportunity for these kind of systems test.

8. Figure New test scenario for our measurement

Recognition difficulties also apply to traffic signs that are fully or partially covered by labels, dirt, or bushes. High speed and bad weather conditions, especially at night, make it difficult for the system to recognize road signs reliably. For the current top speed limitations to appear as accurately as possible, the map of the navigation must be up to date.

9. Figure Visibility traffic sign anomalies in the test environment

We measured the critical point of the traffic sign recognition system is highly automated vehicles. Every single measure, we searched the limit with a predetermined percentage when the system could not recognize the traffic sign with anomalies. [20]

3 Results

The goal of the measurements was to examine the test methodology itself, and which is the critical point of a highly automated vehicle when it cannot to recognize traffic signs with anomalies. From this, one can infer the area to be developed. The darker notation shown what values were critical for each system. [21] In the next tables the "✓"mark said the system could to recognized the traffic sign. The "x" mark said the system could not to recognized the traffic sign.

Mercedes performed best traffic signs recognition covered by a column. The vehicle system isn't sensitive for the position changing, unlike the mud and bush covering. The vehicle performed well with the traffic signs rotation.

*Table 2. Results of **Mercedes**'s recognition system*

1) Column	0%		100%		50%		25%	44%	37,5%	44%
Recognized ?	✓		X		X		✓	✓	✓	✓
2) Poition	0%		100%		-		-	-	-	-
Recognized ?	✓		✓		-		-	-	-	-
3) Mud	0%	100%	87,5%	75%	62,5%	50%	37,5%	25%	12,5%	1%
Recognized ?	✓	X	X	X	X	X	X	X	X	✓
4) Bush	0%		100%		50%		25%	12,5%	5%	-
Recognized ?	✓		X		X		X	X	✓	-

The **Jaguar** was the most sensitive to changing position and mud covering. The vehicle in this test performed moderately at the traffic sign covered by the column. With the position anomaly, the temporary traffic situation was simulated, positioned at a standard height. Here, further extreme values can be tested later with height changing.

*Table 3. Results of **Jaguar's** recognition system*

1) Column	0%	100%	25%	37,5%	44%
Recognized?	✓	✓	✓	✓	X
2) Poition	0%	100%	0,5%	75,0%	87,5%
Recognized?	✓	X	✓	✓	✓
3) Mud	0,5%	0,3%	0,1%	0,05%	-
Recognized?	X	X	X	✓	-
4) Bush	0,0%	100,0%	0,5%	0,25%	0,00125
Recognized?	✓	X	X	X	✓

The **Audi** performed moderately at the traffic sign covered by the column. The traffic sign covered by a column is easily recognizable for the vehicle. The bush and mud hiding is hard than the other anomalies.

*Table 4. Results of **Audi's** recognition system*

1) Column	0%	100%	0,50%	0,25%	0,375%	44%
Recognized?	✓	X	X	✓	✓	X
2) Poition	0%	100%	-	-	-	-
Recognized?	✓	✓	-	-	-	-
3) Mud	100,0%	0,8%	0,5%	0,25%	0,375%	-
Recognized?	X	X	X	✓	X	-
4) Bush	0,0%	100,0%	0,5%	0,25%	0,125%	-
Recognized?	✓	X	X	X	✓	-

All in all, the test scenario can be used to determine the critical values of each vehicle's detection system in the beacon. For later measurements, the grading system could work. The recognized signal receives not only a "✓" but also a value associated with it, in this case, for example, 1 point if the detection system hits the signal at certain anomaly levels. If "x" recognized the traffic sign, it gets a value of 0, then the visibility. The various weaknesses of the sensors can be avoided by using the other sensors at the same time. Therefore, based on the tests, it can be concluded that sensor fusion is the solution for accurate and safe detection.

4 Conclusion

In many cases, the results obtained are impressive, but they are easy to validate and develop the results, and test later. The test scenarios still need improvement despite preliminary measurements and experience. Measurements can be done easily and quickly, possibly with more vehicles. Multiple vehicles are more comfortable to perform with the tests we invent. The results can be well analyzed, and the recognition characteristics, weaknesses and strengths of each vehicle are visible. With the help of the test, the boundary point, the critical point of the system of each vehicle type is evident. Of course, more measurements are needed for full accuracy. **Our goal is to find a suitable, reproducible and effective test procedure for the time being.** In the future, special attention should be given to the increasingly widespread neural networks. The basics of the test are likely to remain unchanged but will require weighting and other anomalies. With this test, both systems and neural networks can be validated. Our future plan that we will use this test procedure and the scenario for attacking neural networks with our optimized traffic signs attack. [27]

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