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Simulation and Validation with Radio-Controlled (RC) Autonomous Vehicles in Roundabout Situation

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Abstract
In the present research paper, the authors provide an extensive overview about a so far uninvestigated approach regarding the research and development (R&D) of Autonomous Vehicle Technologies, an exhaustive investigation concerning the simulation and validation of roundabout situation with radio-controlled (RC) autonomous vehicles, as well as the examination of RC vehicles' applicability in the testing processes of Connected Autonomous Vehicle (CAV) technologies. Through this research project, the authors are offering a thorough analysis concerning the most current Autonomous Driving Systems from the point of view of their operation in roundabout related environments, as well as have developed two small-scaled RC autonomous vehicle models, which are capable of being used in the testing and validation processes concerning research studies related to the field of autonomous vehicles. This paper represents the first of a two-part in-depth examination of the aforementioned subject matter, organized in six sections, each contributing significantly to the realization of the final structure of a unique and comprehensive project.

Keywords
autonomous vehicles, simulation, validation, roundabout scenario, ZalaZONE, radio-controlled (RC) vehicle models

1 Introduction

Section 1 aims to provide a brief outline of all the issues that will be developed in this study, as regards the autonomous vehicles' roundabout related decisions.

Within Section 2, based on research and analysis of the specialty literature and the cited bibliographical sources, the most essential information is presented regarding the topic of the paper.

Section 3 is divided into Subsections 3.1 and 3.2, both dedicated to the purpose of outlining the methodology of the research.

Based on the theoretical knowledge gathered within Section 2, in Section 4, the main parameters of the decision situation were determined, and a commonly utilized modeling environment was used in the simulation processes.

Conclusions issued based on the aforementioned find themselves in a clear form in Section 5 of the study, along with the obtained results.

In Section 6 the new research directions opened by the results already obtained are presented.

The end of the paper is dedicated to the Acknowledgment, as well as for the References, mentioning the used bibliographic sources.

2 State of the art literature review

Today's vehicles already have several Driver Assistant Systems and in the near future, Highly Automated Vehicles will also appear in road transport. *Higher automation* levels rely on *disruptive technologies* that cannot be tested and approved in the former way. To be able to guarantee future road safety also *disruptive testing and validation methods* are required. The complexity of the systems and the stochasticity of the potential traffic situations demand new approaches with *different testing levels and approval layers* (Szalay et al., 2017).

Driving a road vehicle is a very complex controlling task, so substituting the human driver with a computer is a real challenge also from the technical side. Since autonomous driving functions must handle nearly countless

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traffic participants and various situations, most companies developing such technologies began testing on *public roads*, which became possible due to the amendment of laws in several progressive countries or states worldwide, for example leading states such as California, the Netherlands and from 2017 *Hungary* (NFM, 2017).

However, recent regrettable incidences highlight the *risks of public road testing*, and strengthen the role of *closed proving grounds*, as well as specially designed and constructed *controlled urban-like test areas*, which can authentically represent real-world environments (Németh et al., 2019).

Due to the new components and increased in-vehicle system complexity, vehicle testing and validation has become different from what it was earlier. Testing the vehicle, the driver-controller and the traffic situations together require *new testing methods and strategies*. The aim is the same as earlier, to guarantee road safety with reliable operation of the systems.

In the case of the present project, the authors will mostly concentrate on *roundabout-related traffic situations* (though the applicability of these presented methods is certainly not limited only to roundabout-testing), presenting not only the most commonly used *simulation and validation techniques* regarding these scenarios, but the more disruptive, relatively new technologies as well, particularly focusing on the examination of *radio-controlled (RC) cars' usability* in the research and development (R&D) of Connected Autonomous Vehicles (CAV).

3 Research method

The testing of connected and automated vehicles typically focuses on *traffic situations*. There are studies where these traffic situations are classified, in order to simplify the tests, but the typical property of traffic situations is the *stochasticity*.

It is impossible to predefine every traffic situation, and it is impossible to prove the reliability of Connected and Automated Vehicles without public road tests. The purpose is to test the systems step by step from the simulation environment to the public road.

Step by step testing results in a cost- and time-efficient demonstration of the reliable operation of CAVs. Therefore, there are *different testing environments* or *levels*, based on which autonomous vehicles are being tested, as summarized below by Fig. 1.

High-level automated driving functions are based on Advanced Driver Assistance Systems (ADAS), which require *multiple validation process types*. Testing during

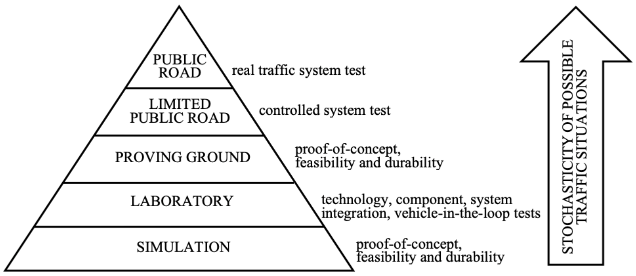

Fig. 1 Autonomous vehicle testing and validation pyramid (Szalay, 2016)

the product development phase includes a very wide range of processes covering *component and system-specific testing.* These types of validation processes or testing commonly use the well-known *V-model* and *"in-the-loop" testing methods*, as detailed below (Németh, 2017).

In-the-loop simulation is a quick and cost-effective testing method using virtualization of specific subsystems belonging to a complete system (set of components) or vice versa, and therefore does not require the physical presence of the real component until the full physical implementation phase, except for the actual physical component being tested. The different levels of this method can be placed in the *V-model*, where some of these are used in analytical steps or tasks, and others in testing and validation processes as seen in Fig. 2.

Using the *Model-in-the-Loop (MiL) method*, the created models or algorithms are integrated into a virtual simulation environment with the help of a model-based software. In the case of this present project, this MiL method is represented by the *simulation phase*, detailed in Section 4. All necessary components must be provided as virtual modules because in this phase the hardware is usually still unknown. This way, several fault factors can be identified in this early stage and the development risk can be reduced.

In the case of the *Software-in-the-loop (SiL) method*, specific software must be created using the system's or subsystem's logical architecture, which will, in turn, produce very similar real-time behavior as compared to the target

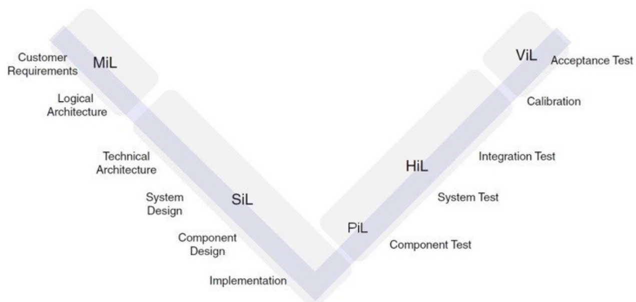

Fig. 2 In-the-loop simulation methods in the V-model (Németh, 2017)

system. SiL offers the possibility to check or analyze the specification of individual components and to easily adjust them if necessary.

The *Processor and Hardware-in-the-loop (PiL, HiL) method* can be used after the virtual integration of the whole system is done and checked by using MiL and SiL. Firstly, the individual components are verified with *PiL,* and subsequently, the interaction of these components is tested with *HiL*, which has more steps depending on how many subsystems are tested and is actually built upon PiL testing.

The *Vehicle-in-the-Loop (ViL) method* is not a classical in-the-loop method, because it was developed specifically for the testing of ADAS functions, to demonstrate a vehicle's or its subsystem's technical functionality. *ViL* provides the foundation of the *Scenario-in-the-loop (SciL) method*, with the help of which more or less the entire vehicle system can be tested, except for its sensory system or perception layer (Bock, 2008).

The *SciL* concept is the extended version of the *Traffic-in-the-Loop (TiL) simulation method*, which was primarily created for testing the autonomous driving functions in collision critical situations. With TiL the complete vehicle and its self-driving subsystems can be tested, including its perception layer. The foundation of TiL and SciL is ViL (Németh, 2017).

3.1 RC cars' applicability as an R&D method

In the case of the present project, the authors are mostly focusing on *roundabout-related traffic scenarios*, hoping that more relevant data and conclusions could be obtained this way, rather than analyzing situations, where more connected consecutive maneuvers are taking place, however, this does not mean that the applicability of the presented research method is limited only to roundabout-testing, in fact, on the contrary, it could have a much more *global usability*.

A *roundabout* is defined as a special case of a circular one-way intersection or a road junction, at which the traffic participants are moving in one direction around a central island, with the intention of changing direction and reaching one of the roads converging on it, thus improving the traffic flow, minimizing the congestion, while increasing road safety.

Decision making about whether to enter into a roundabout or to stop before it are multi-criteria situations, that are quite complex not only for autonomous vehicles, but for human drivers as well (Tollner et al., 2018).

Therefore, if a traffic scenario as sophisticated as a roundabout situation could be automated by an Autonomous Driving System, the whole *automated urban mobility sector* could benefit from it. This requires a significant amount of simulation, testing and validation data, which cannot come only from proving ground or public road testing, *new testing methods and strategies* are needed (Ferencz, 2019).

As a consequence, because real-life testing procedures such as *public road testing* or *closed proving ground tests* present a higher risk, are far too complex and expensive to be realized continuously in any given situation with the two costly equipped autonomous vehicles, a much more sustainable, *alternative solution* has to be found, such as the *small-scale testing procedure*, realized with the significantly cheaper *RC models* of the two vehicle.

With the help of these models, development time could be reduced drastically, and only the most critical case scenarios need to be tested in real environments, hence obtaining *more testing data* with *less time and costs*.

3.2 Connection to ZalaZONE

The main advantage of test tracks is *predictable safety*, since they are not publicly accessible. Because there are many systems that require different test equipment, a *universal test track* can serve all expectations, as can a unique test track like the *new Hungarian proving ground at Zalaegerszeg*.

At the beginning of 2016, the Hungarian government decided to build an automotive proving ground primarily for automated and connected vehicles. The aim of the investment is to make the Hungarian automotive industry more competitive, which is a major industrial sector of the country. The chosen place is near *Zalaegerszeg*, the size of the area is *250 [ha]*.

The proving ground is suitable for a *wide range of vehicle and traffic tests*, for conventional, connected and automated vehicles as well, having integrated urban areas with interconnecting rural roads, highway areas, and other high-speed proving ground modules, thus allowing for testing the *complete range of autonomous functions*. Test processes can be performed for *certifications*, to *control regulations*, for *R&D purposes* and for *educational aims*.

Consequently, the Hungarian test track at Zalaegerszeg, or *ZalaZONE*, is a special proving ground, which combines traditional test track features focusing on driving safety and stability with an R&D infrastructure of a multi-level system of validation for future connected and automated vehicles. The specific elements of the proving ground are defined by the *pyramid of testing and validation* (see Fig. 1).

The proving ground provides not only *dynamic tests* for conventional vehicles, but it also allows *validation tests* for self-driving cars and electric vehicles. This test track is an optimal test environment for future vehicles and their communication technologies, it contributes to the testing of these from the concept phase to the final product status.

The test track has the following parts:

- *urban tracks* with complex city road elements, such as intersections with traffic signs, roundabouts, parking spaces and buildings, fitted with special "Smart city" equipment as well (e.g. moving obstacles or intelligent traffic lights);
- *rural roads* aimed to test the vehicles at lower velocities, the shape of the roads being designed to test the maneuverability of autonomous systems;
- *general highway road*, the purpose of which is to test high-speed autonomous functions, such as lane-keeping or changing;
- *alternative grounds* designed to test the vehicles on different kinds of roads, with different qualities or slope inclinations, or to perform measurements;
- *dedicated grounds* developed to test Vehicle-to-everything (V2X) communication technologies.

As it is shown above in the testing and validation pyramid (see Fig. 2), between the quite well controlled proving ground tests and the fully open public road testing there has to be an intermediate testing and validation layer.

This layer would be *a controlled area of a city*, one of the most important parts of the whole proving ground, where the traffic regulations are modified, in order to guarantee safety. This controlled area would be a dedicated "Test city", or, in the case of the Hungarian proving ground, a so-called *Smart City* environment.

In summary, this controlled area can serve two aims:

- testing the automated vehicles, using the *controlled stochasticity* of the partially public road, the modified regulation of the traffic could be time-dependent and dynamically changeable in order to always reach the safety objectives;
- apart from the tested self-driving functions of the vehicles, the controlled area could be a Smart city too, a place where connected car features and *smart traffic control systems* could be tested among the conventional traffic stakeholders (Automotive Proving Ground Zala Ltd., 2019).

Consequently, the ZalaZONE's *Smart City Zone* is a city-like area, designed to provide realistic traffic circumstances in a closed environment, where that particular roundabout is situated, on the basis of which not only the virtual simulation environment, but the small-scaled test roundabout will be designed, developed and constructed as well. Since the geometry, design and structure of this considered roundabout is so similar to any other public road roundabout, the obtained simulation/validation results and conclusions, issued at the end of this study, will be as precise as possible.

In Fig. 3 the new *Hungarian Automotive Proving Ground's design* is shown, while Fig. 4 presents the *Smart City Zone's position* (and the considered roundabout in it), related to the ZalaZONE test track.

4 Simulation with PreScan

Simulation is the mathematical modeling of a well-defined part of the real world, in this case, the *virtual representation of the test environment*.

To reach evaluable results by simulation it is important to define the required complexity of the models. Knowledge of capability, the neglected effects and the limits of the simulation model make the design process efficient. There are *two types of commercial automotive*

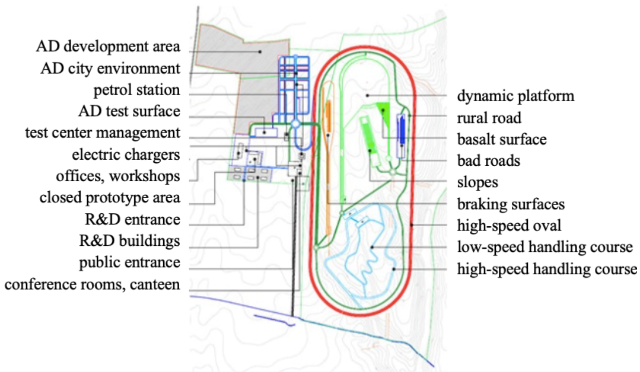

Fig. 3 The test track design of the Hungarian Automotive Proving Ground at Zalaegerszeg and its different elements dedicated to autonomous vehicle testing and validation (Szalay et al., 2017)

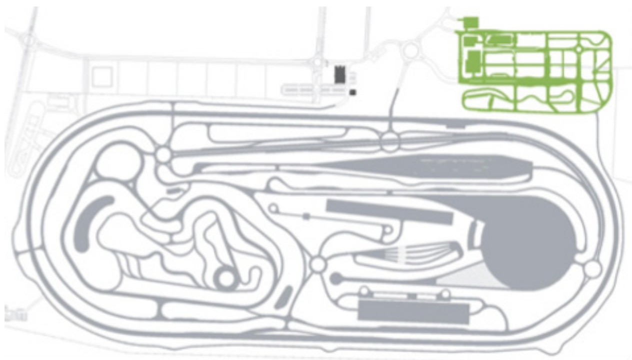

Fig. 4 Smart City Zone's position related to the ZalaZONE test track (Automotive Proving Ground Zala Ltd., 2019)

simulation software used for modeling road vehicles and traffic situations.

The *first type,* which focuses on *vehicle dynamics*, is the integrated vehicle dynamics simulation software. In conventional vehicles, the most important requirements are safety and easy handling.

Designing a car according to these expectations requires the simulation of the vehicle's dynamical behavior, in order to analyze the system's operation: engine performance, brake performance, suspension performance, as well as their harmonization. These simulation environments implement the longitudinal, lateral and vertical vehicle dynamics equations. The role of the stochasticity is small here.

The *second type* focuses on *traffic situations*. These simulation environments have been developed for transport engineers to design the traffic flow of cities. In this kind of software the vehicle models are very simple. The aim is to make the transport in complex traffic networks faster.

The simulation environment, which represents the future for automated vehicles, practically integrates these two key features, where the vehicle is handled as part of the environment, not as an independent system.

A typical example of a virtual environment like that would be *PreScan*, a software tool aimed to simulate automated vehicles in every SAE level, as well as to generate and control difficult traffic scenarios with the integration of real vehicle dynamics, road and driver models.

We will use PreScan as a virtual simulating and development environment to evaluate ADAS functions, as well as Intelligent Vehicle (IV) systems that are based on various technologies, such as Radio Detection And Ranging (RADAR), Light Detection And Ranging (LiDAR), video cameras, ultrasonic sensors, Global Positioning Systems (GPS), Vehicle-to-vehicle (V2V) or Vehicle-to-infrastructure (V2I) communication systems, along with others.

The simulation process with PreScan consists of *four phases*: building the respective scenario, adding the appropriate control systems, modeling the sensor system, respectively running the experiment.

Building the scenario is carried out using PreScan's dedicated pre-processor module. The *control systems* (decision-making algorithms, signal processing algorithms, etc.) are all introduced, being compatible with PreScan's software, in a MATLAB/Simulink session. *Sensors* are either defined in PreScan, as in the case of the present project, or using MATLAB/Simulink, respectively *running the experiment* also takes place in the MATLAB/Simulink environment (Tass International, 2018).

4.1 Parameters

In Table 1 the main dimensions of each of the two vehicle model are presented, both their real-life and small-scaled dimensions, used not only in the simulation process, but at the testing and validation phase as well.

During the process of the simulation, we came to the conclusion that small-scaled dimensions of 1:10 ratio cannot be implemented in the PreScan1 software, the simulation being a mathematical modelling of a well-defined part of the real world, it only can be run, obtaining valid results, with real world dimensions and scenarios. For this reason, the simulation will be a virtual reproduction of the real-life testing scenario.

4.2 Scenario conditions

The considered roundabout is a *standard, single-lane roundabout*, with a 32.5 [m] diameter. It has four legs and each adjacent leg angle is assumed as 90 [°]. The reviewed initial scenario is set to be an investigation of an *urban condition* with the two considered autonomous vehicles (Cao and Zöldy, 2019).

Fig. 5 outlines the ZalaZONE Smart City Zone's roundabout features, respectively Fig. 6 shows the simulated roundabout's layout and structure, based on which the small-scaled test track will be developed and constructed, while in Table 2 its exact dimensions are specified.

Table 1 Dimensions of the considered vehicle models

Real-life / Small-scaled dimensions	Smart Fortwo	Honda CR-Z
Length, [m]	2.5/0.25	4.08/0.408
Width, [m]	1.515/0.1515	1.740/0.1740
Height, [m]	1.529/0.1529	1.395/0.1395

Fig. 5 The considered roundabout, situated in the ZalaZONE proving ground's Smart City Zone (Automotive Proving Ground Zala Ltd., 2019)

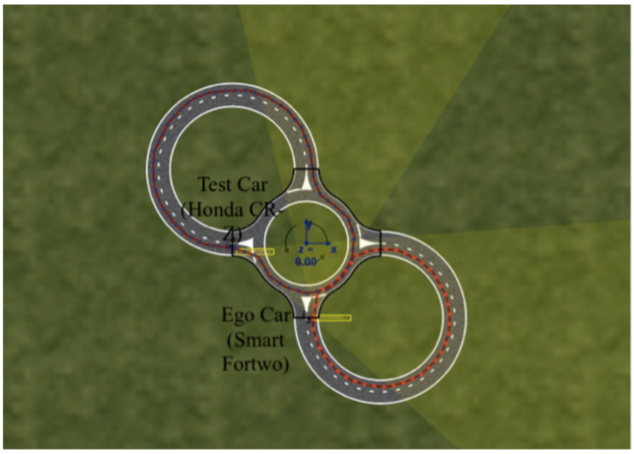

Fig. 6 The simulated roundabout's layout and structure built in PreScan, based on which the small-scaled test track will be realized

In any given roundabout related traffic situation, the speed of the vehicles is reduced once approaching to the yield line of a given roundabout, regardless of vehicle type, respectively low speed is being kept once inside the circulatory roadway, followed by an acceleration after exiting the roundabout (Vaiana et al., 2012).

In the considered situation, the *test car (Honda CR-Z)*, which represents the traffic, arrives from the left leg of the roundabout, and has the priority, while the *ego car (Smart Fortwo)*, the vehicle which we want to teach to drive correctly, comes from the lower leg of the roundabout (see Fig. 6). This vehicle takes the decision whether to enter into the roundabout or to stop before it, whether rejecting or accepting the gap (Shaaban and Hamad, 2018).

Based on the following descriptive analysis *two scenarios* are defined, situations that are used as input data throughout the simulation process.

In the *first scenario*, the *test car* arrives from the left leg of the roundabout, with the intention of taking the third exit, i.e. the upper leg, enters the roundabout first, having the priority. Meanwhile, the *ego car*, coming from the lower leg of the roundabout, with the intention of going right at the intersection, ergo taking the first exit, is stopping before it, since the test car already entered the roundabout.

In the *second scenario*, similar to the previous situation, the *test car* arrives from the left leg of the roundabout, with the intention of taking the third exit, i.e. the upper leg, enters the roundabout first, having the priority. This time, however, the *ego car*, coming from the lower leg of the roundabout, with the intention of going right at the intersection, is not stopping before the roundabout, but enters as well, getting ahead of the test car, the waiting time will be minimized, thus improving the fluency of the traffic.

Table 2 The considered roundabout's dimensions

Real-life / Small-scaled dimensions	Parameters, [m]
Inscribed circle diameter	32.5/3.25
Entrance width	3.61/0.361
Exit width	3.61/0.361
Approach/Departure width	3.61/0.361

4.3 Building the respective scenario

The vision for PreScan is to bridge the gap between simulation and validation by offering virtual verification capabilities. The software consists of *three main modules;* these are the *Pre-processor*, also known as the *Graphical User Interface (GUI)*, the *Engineering Workspace* and the *VisViewer*.

The *GUI*, also called *Experiment Editor*, is used to define and modify experiments. PreScan experiments typically contain a definition of the world (roads, trees, buildings), definitions of so-called *actors* (cars, pedestrians, etc.) – each of them having their own controller and/or dynamics, and/or sensor models, and other information like which car is driving according to which trajectory profile.

In the case of both discussed scenarios, the infrastructure is the same, consequently, we have two actors with the same configurations. Actors are those objects that play an active role in the experiment, in this case, the two vehicles.

The maneuver of these was defined with the specialized tools available in the GUI, by defining a so-called *path* from *segments*, and assigning an actor to it, thus obtaining a *trajectory*, which contains speed, profile, and path. By synchronizing actor positions, through introducing delay times at the start or at the end of a trajectory, the trajectories are shifted in time in such a way that the actors will be at the right location at the right time, thus obtaining the mentioned traffic-flow in the case of the second scenario (Almroth, 2013).

After that, the models, with all the information created in the GUI, are gathered and compiled for simulation into the dedicated MATLAB/Simulink session, known as the *Engineering Workspace* (commonly referred to as the *Compilation Sheet).* The compilation sheet is the prime interface for the engineer to work on their algorithms, all information essential to run an experiment is effectively collected in this Simulink session sheet. Elements the user will find in this module include Simulink models selected in the GUI, such as dynamics models, trajectory information defined using the GUI, respectively ports to PreScan's standard sensor models and to the PreScan Simulation Engine.

There are multiple reasons why MATLAB/Simulink was selected for this purpose, but most importantly because MATLAB/Simulink is the automotive world's most preferred choice for simulation purposes. Many control and decision algorithms are predefined and already available in MATLAB/Simulink, and can be easily imported and reused with any conversion as such, the scenario can be redefined repeatedly, both providing and supporting, in connection with the proving ground modules, a highly flexible and reproducible testing environment (Németh et al., 2019).

The simulation is visualized in the *VisViewer* module, a high-end 3D visualization viewer. The scenario can be zoomed to its outer boundaries, while obtaining multiple viewpoints from the simulated experiment.

The sensors are simulated, and the positions of the actors are calculated with the help of the *Simulation Engine*. This module is linked 1:1 to PreScan's MATLAB/Simulink session. The *Process Manager* supervises the main modules, including the Simulation Engine. It synchronizes and schedules the various information flows between the modules (Tass International, 2018).

4.4 Modelling the sensor system

Even though the two real-life vehicles, the Smart Fortwo and the Honda CR-Z, and their driving systems are equipped with a much more complex and sophisticated hardware system, the functioning principle of those are the same as in the case of the small-scaled RC models, the detection of other actors and road markings being realized by the front-facing automotive cameras. The control system in the case of the real-life models is a central on-board computer, while in the case of the small-scale models a single-board computer or microcontroller.

The *environmental perception* is formed through the *mono-vision system*, which can observe or measure vehicle dynamics and trajectories, the road and other road users, the traffic, the objects around the vehicle or other environmental conditions.

This *mono-vision sensor* or *camera* is defined relative to a fixed point of the actor. For the vehicles, this point is located at the middle of the rear axle, at ground level. The sensor readings are expressed in a spherical coordinate system with angle definition. With the help of the vision systems the readings are combined to obtain a better perception of the actual situation, and to maximize the decision-making capabilities through extensive data processing.

5 Results and conclusion

Taking into account all the above, some clear outcomes and conclusions can be identified and specified, most importantly the fact that increased usage of highly-automated and well-controlled *proving ground test environments* are becoming more and more essential.

The specialized CAV testing facilities such as *ZalaZONE* hold the basic tools to forge forward to meet the latest *testing, validation and regulation challenges* related to the field of self-driving vehicles, forging activities that are already underway in several running R&D projects at the Hungarian proving ground.

Besides that, however, new, *alternative testing and validation methods and strategies* are still needed in the field of research and development of future mobility technologies, wherewith development time could be reduced drastically, with only the most critical case scenarios need to be tested in real environments, hence obtaining more testing data, with less time and costs. A possible, as well as perfectly adequate example for this kind of method is the one provided and extensively presented within this study: *radio-controlled, small-scaled vehicle models, tested on model proving grounds*.

As far as the *simulation process* is concerned, also essential discoveries have been found, such as the fact that small-scaled dimensions of 1:10 ratio cannot be implemented in the virtual simulation environment, as initially proposed, and for that reason, the simulation will be a *virtual reproduction of the real-life testing scenario*. Moreover, an *ideal test track geometry* has been developed as well, along with the *future testing scenarios*.

In this sense, therefore, the first phase in the process of autonomous vehicle testing and validation, the base of that frequently cited pyramid, has been concluded, following the *actual testing procedure*, detailed in a future study.

Last but foremost, the authors also hope that new testing and validation methodologies can be based on this extensive investigation, that this study could be a valuable support direction in the field of the above mentioned subject matter.

6 Future work

In the following *second part* of this two-part exhaustive investigation related to the various research processes of Connected Autonomous Vehicles in predefined roundabout situations, a greater emphasis will be placed on the validation processes regarding all the results and conclusions obtained over this present article, through the actual realization of the hardware and software of the small-scaled, radio-controlled models, followed by the extensive practical testing of these and the two real-life vehicles.

Additionally, a new potential R&D field and direction could be the possible realization of *SiL situations*, along with the enhancement of the *complexity of the roundabout* scenario with additional lanes, entries and exits, pedestrian crossings, separator islands, variable weather conditions or road markings.

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References

Almroth, M. (2013) "Simulation, validation and design of cooperative driving systems using PreScan", [pdf] MSc Thesis, KTH Royal Institute of Technology. Available at: http://www.divaportal.org/smash/get/diva2:614537/FULLTEXT01.pdf [Accessed: 27 September 2019]

Automotive Proving Ground Zala Ltd. "Track vision - ZalaZone", [online] Available at: https://zalazone.hu/en/ [Accessed: 27 September 2019]

Bock, T. (2008) "Vehicle in the Loop – Test- und Simulationsumgebung für Fahrerassistenzsysteme" (Test and simulation environment for driver assistance systems), [pdf] Audi Dissertationsreihe, Cuvillier Verlag, Göttingen, Germany, Paper no.: 1285. Available at: https://cuvillier.de/uploads/preview/public_file/2747/9783867277273.pdf [Accessed: 27 September 2019] (in German)

Cao, H. Zöldy, M. (2019) "An Investigation of Autonomous Vehicle Roundabout Situation", Periodica Polytechnica Transportation Engineering. https://doi.org/10.3311/PPtr.13762

Ferencz, C. (2019) "Implementarea unui sistem de conducere autonomă" (Implementation of an Autonomous Driving System), BSc Thesis, Universitatea Tehnică din Cluj-Napoca. (in Romanian)

Ministry of Development of Hungary (NFM) (2017) "KöHÉM Decree in Hungarian Official Gazette (Magyar Közlöny)", no. 11/2017 (IV.12.).

Németh, H. (2017) "Proving ground test scenario simulation for autonomous vehicles", Automotive Proving Ground Zala Ltd, Zalaegerszeg, Hungary, Rep. 34/2017.

Németh, H., Háry, A., Szalay, Z., Tihanyi, V., Tóth, B. (2019) "Proving Ground Test Scenarios in Mixed Virtual and Real Environment for Highly Automated Driving", In: Proff, H. (ed.) Mobilität in Zeiten der Veränderung, Springer Gabler, Wiesbaden, Germany, pp. 199–210. https://doi.org/10.1007/978-3-658-26107-8_15

Shaaban, K., Hamad, H. (2018) "Group Gap Acceptance: A New Method to Analyze Driver Behavior and Estimate the Critical Gap at Multilane Roundabouts", Journal of Advanced Transportation, 2018, Article ID: 1350679. https://doi.org/10.1155/2018/1350679

Szalay, Z. (2016) "Structure and Architecture Problems of Autonomous Road Vehicle Testing and Validation", presented at the 15th Mini-Conference on Vehicle System Dynamics, Identification and Anomalies – VSDIA. BME, Budapest, Hungary, Nov. 7–9, 2016.

Szalay, Z., Nyerges, Á., Hamar, Z., Hesz, M. (2017) "Technical Specification Methodology for an Automotive Proving Ground Dedicated to Connected and Automated Vehicles", Periodica Polytechnica Transportation Engineering, 45(3), pp. 168–174. https://doi.org/10.3311/PPtr.10708

Tass International (2018) "PreScan, (Version 8.4.0)", [computer program] Available at: https://tass.plm.automation.siemens.com/prescan [Accessed: 27 September 2019]

Tollner, D., Cao, H., Zöldy, M. (2018) "Artificial Intelligence Based Decision Making of Autonomous Vehicles Before Entering Roundabout", presented at the 18th IEEE International Symposium on Computational Intelligence and Informatics, Budapest, Hungary, Nov. 21–22, 2018.

Vaiana, R., Gallelli, V., Iuele, T. (2012) "Simulation of Observed Traffic Conditions on Roundabouts by Dedicated Software", Procedia - Social and Behavioral Sciences, 53, pp. 741–753. https://doi.org/10.1016/j.sbspro.2012.09.924