Simulating and AR/VR Visualizing AstaZero

Public report

Project within Trafiksäkerhet och Automatiserade Fordon
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Date 2023-05-26

Jan 2019

Picture from project

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.

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1. Summary

This project was undertaken with the main objective to deepen AstaZero's understanding and knowledge about simulation and related processes to enhance the testing and validation of Advanced Driver-Assistance Systems (ADAS) and Autonomous Driving (AD) vehicles. Five key subtopics within simulation that held potential were identified, forming the structure for the five work packages executed during the project.

Throughout the project, numerous advancements were made in various aspects of simulation and its applications. In the domain of 3D model generation (WP1), methodologies and multiple 3D models over AstaZero proving ground were successfully created, serving as a robust foundation for future development and research. Future research is expected to focus on synthetic data generation and automated creation of 3D models using sensor fusion and machine learning.

The AR and VR (WP2) package successfully created an AR application that allows test engineers to visualize virtual objects during test activities. Future research aims to enhance the immersive AR experiences during tests and facilitate more Human-Machine Interface (HMI) studies.

Work Package 3 addressed system integration and communication, enabling connection of simulation processes to the test control system. Future research in this area will explore the application of 5G communication to distribute sensor data, potentially reducing latency and increasing bandwidth.

The OpenSCENARIO work package (WP4) succeeded in increasing knowledge of creating OpenSCENARIO 1 scenario files and opened avenues for creating a larger scenario database.

Work Package 5 developed various rig applications that demonstrated the potential use of different hardware rigs for testing simple ADAS functionalities, by using simulated or emulated sensor data.

Throughout the project, a hands-on approach was adopted to encourage learning by doing, reading research papers actively, and engaging in industry and internal discussions. The project has significantly contributed to the simulation and digital twin technical roadmap within AstaZero, enabling the company to actively participate in technical conversations and collaborate with more partners in future research projects.

2. Sammanfattning på svenska

Detta projekt syftade till att öka AstaZeros kunskap inom simulering för att förbättra testning och validering av avancerade förarassistanssystem (ADAS) och autonoma körningar (AD). Projektet har identifierat och utforskat fem nyckelämnen inom simulering, vilka utgör grunden för projektets arbetspaket.

Projektet har gjort framsteg inom 3D-modellgenerering, skapat en AR-applikation för att visualisera virtuella objekt under tester, tagit fram lösningar för systemintegration och kommunikation mellan simuleringar och testkontrollsystem, ökat kunskapen om att skapa OpenSCENARIO 1 scenariofiler, samt utvecklat olika rigg-applikationer för att testa olika ADAS funktioner i rigg.

Genom hela projektet har en hands-on-ansats antagits, vilket har bidragit till att öka kunskapen inom simulering och digitala tvillingar, och därigenom göra det möjligt för AstaZero att vara en aktiv part i tekniska samtal och samarbeta med fler partners i framtida forskningsprojekt.

3. Background

As Autonomous Driving (AD) and Advanced Driver-Assistance Systems (ADAS) keep developing, the amount of testing and validation needed for these systems increase (AVL 2023) the higher on the SAE's scale of automation (SAE 2021). As the sophistication of these technologies continues to grow, matching the complexity of the real-world environments they operate in, it's recognized that for a thorough and effective validation of these systems, virtual testing methods must be integrated with traditional physical testing (Schilling and Schultz 2016).

AstaZero

AstaZero is a company that initially focused on conducting traditional track testing for active safety systems. However, its role has expanded to include comprehensive testing for future automated systems. AstaZero has become a crucial player in the development of advanced testing methods for autonomous vehicles.

Simulation

A key factor in the development, testing, and validation is the use of simulation. Simulation has emerged as an indispensable tool in the development pipeline of ADAS and AD systems. It allows developers to create a controlled virtual environment that mirrors real-world scenarios, enabling extensive testing and refinement of the algorithms that power these systems. The scenarios cater to a wide range of driving conditions including diverse weather patterns, traffic situations, pedestrian movements and virtually any other potential circumstance a vehicle might encounter on the road.

Of particular significance is the use of simulation for testing "edge cases". These are unusual, rare, or extreme situations that a vehicle may encounter. Given the impracticality or inherent risk of reproducing these cases in a real-world setting, simulation provides a safe and efficient alternative. For instance, developers can simulate scenarios such as a pedestrian suddenly stepping into the road or unexpected severe weather events.

Simulation also provides the flexibility to validate the performance of ADAS and AD systems across different vehicle models, hardware configurations and software versions. This versatility ensures that no matter the specific setup, the systems will function correctly and safely. This opens the possibility for third party organizations to perform more testing on AD and ADAS vehicles today to ensure a higher level of safety on these systems to help the drive towards vision zero.

Moreover, simulation contributes significantly to the compliance with safety standards and regulations. Regulatory bodies are increasingly recognizing simulation as a crucial component in demonstrating the safety of ADAS and AD systems (Euro NCAP 2022) (UNECE 2022).

3D-Generated Environments

In recent years, the use of 3D environments and synthetic data generation has surged, becoming integral in the training, validation, and testing of various machine learning systems, particularly within perception tasks for autonomous vehicles (Csanády 2022). These 3D-generated environments can mimic complex, real-world scenarios with high fidelity, providing an effective tool for creating varied and unpredictable situations to train and test autonomous systems.

One example of this approach is software such as Omniverse™ from Nvidia (NVIDIA 2023), solutions from Applied Intuition (Applied Intuition 2023), and others. These platforms can generate sophisticated 3D environments and scenarios, which allow autonomous systems to learn and adapt to diverse situations before they encounter them in the real world.

Further advancements in the field are being made through automation in 3D-model generation. With the growth of machine learning and artificial intelligence, algorithms are now capable of automatically creating detailed, accurate 3D models based on a variety of inputs, such as text descriptions, images or even paintings (Lin, et al. 2023).

Photogrammetry, the process of creating 3D models from 2D photographs, is also witnessing substantial improvements. Innovative approaches such as Neural Radiance Fields (NeRF) and its instant variants provide promising avenues for creating highquality 3D environments. This technique leverages the power of machine learning to convert 2D inputs into detailed 3D models, making the process faster and more efficient (Mildenhall, o.a. 2021).

These advancements in 3D environment generation play a crucial role in the development of AD and ADAS technologies. By providing a means to extensively test and train these systems in a variety of scenarios, 3D-generated environments are making significant contributions to the safety and reliability of future autonomous vehicles.

Augmented, Virtual and Mixed Reality

Augmented reality (AR), virtual reality (VR), and mixed reality (MR) are three innovative technologies that have been increasingly integrated into various industries, including the automotive sector. They play an instrumental role in the development and testing of ADAS and AD systems due to their ability to simulate and analyze an extensive array of driving scenarios safely and efficiently (Riegler, Riener and Holzmann 2021).

AR overlays computer-generated images onto the real world, creating a composite view that enhances the user's perception of reality. In the context of ADAS and AD testing, AR can simulate real-world scenarios on controlled tracks. For example, developers can overlay and visualize virtual pedestrians, vehicles, or obstacles onto the test track while an ADAS-equipped prototype car is driven. This combination of virtual and real-world elements enables a robust testing of the vehicle's responses to diverse scenarios with substantially less risk involved.

VR, in contrast, immerses the user in a fully computer-generated environment. In the realm of ADAS and AD testing, VR's primary application lies in virtual prototyping and extensive simulation. Before real-world testing, systems can be modeled and tested in a VR environment that mirrors real-world conditions. This capability is particularly valuable for examining edge cases or rare situations, such as extreme weather conditions or unusual road hazards, which may be hazardous, difficult, or even impossible to arrange.

MR, a blend of AR and VR, allows users to interact with both real and virtual environments simultaneously. In the context of ADAS and AD systems, MR could simulate complex situations involving both physical and virtual elements. This might include, for example, a real car interacting with virtual traffic and pedestrians on a test track, providing even more nuanced and complex scenarios for testing these systems and driver response.

Furthermore, these technologies have substantial implications for training. VR and MR, for example, offer immersive experiences that can help humans better understand how to interact with ADAS and AD systems. These hands-on experiences significantly enhance the effectiveness of the learning process.

Each of these technologies—AR, VR, and MR—brings unique strengths to the testing, development, and validation process of ADAS and AD systems, providing a more comprehensive and multifaceted approach to ensure these systems are safe, reliable, and effective.

OpenSCENARIO

OpenSCENARIO is an open standard created by ASAM (ASAM 2023) that provides a standardized format for defining and describing driving scenarios in an XML-based file format. It forms an integral part of the testing and validation process for autonomous driving and ADAS systems.

The primary benefit of using OpenSCENARIO is its ability to standardize the representation of driving scenarios. This standardization facilitates effective communication and collaboration between different teams working on AD and ADAS systems, such as software developers, testers, and even regulatory bodies. It ensures consistency in how scenarios are defined and interpreted, leading to more reliable and reproducible testing processes.

In the context of autonomous driving, OpenSCENARIO can be used to define complex driving scenarios with multiple entities like vehicles, pedestrians, and environmental conditions. These defined scenarios can be simulated in different virtual environments, facilitating comprehensive testing of the ADAS and AD systems under various conditions.

The use of OpenSCENARIO contributes significantly to the drive towards 'Vision Zero' – the goal of no fatalities or serious injuries in road traffic. By creating and testing a vast array of possible real-world scenarios, engineers can better equip autonomous systems to handle challenging situations safely.

Importantly, OpenSCENARIO integrates well with other tools in the autonomous vehicle development pipeline. For instance, it uses OpenDRIVE from ASAM, an open standard for the logical description of road networks, as backend map. An accurate OpenDRIVE map is also a HD (High Definition) map which creates an even more comprehensive and accurate simulation environment.

The application of OpenSCENARIO is not restricted to any specific software or simulation environment, making it a versatile tool for organizations working on ADAS and AD technologies. As an open project, OpenSCENARIO continues to evolve with contributions from the global community driving its ongoing development and enhancement.

4. Purpose, Research Questions and Method

The greater purpose in this project was to increase the knowledge within AstaZero about simulation and its related processes to perform tests and validation for ADAS and AD vehicles to increases and better understand:

1. How ADAS and AD vehicles are tested during development today and in the future.
2. Increase efficiency for tests performed on the proving ground and increase usage and efficiency of the proving grounds track time.
3. Advance the topic enough in-house to be able to be a part of the technical conversation with external partners to create new research projects with more partners.

The simulation topic within ADAS and AD is large, therefore before the project started AstaZero identified five subtopics within simulation that showed potential. Then concretized and limited the simulation topic scope. These subtopics are the same as described in the project applications five work packages.

The work methodology used within this project started by creating a small team that works within the simulation and digital twin topic. The team follows a (Radigan u.d.) work method to develop code, systems, and methodology to fulfill the five work packages described in the project application. A hands-on approach was in general adopted where we learn by implementing, actively reading research papers, and talking to industry and internal needs. More of the results from this approach will be described in the result section.

5. Objective

The objectives and the methods developed in the project is mentioned in the project application work packages. To get an accurate understanding of them, and to easier understand what have been done within this project, every work package is described in table form below. This is the same as they were described in the project application with the difference that they are translated to English. The tables also show the different objectives in each work package as given in the project application.

Table 1 Translation of work package 1 from the project application, Including work content, method, delivery, and objective.

WP 1	3D-Enviroments
Description of contents	Create 3D meshes in the necessary formats required for simulation, such as .OBJ and FBX, of the static environments at AstaZero. Today, the already existing OpenDRIVE maps over AstaZero can be used to create these formats. For the static simulation environment, moving objects are needed. 3D meshes for these are created using sensor data from, for example, LIDAR.
Method/approach (when relevant)	Investigate existing software on the market today that can convert OpenDRIVE to the desired 3D format. Also, examine the workload of developing a converter from OpenDRIVE to the desired 3D format for the static environment. Scan relevant objects that are not part of the static environment and generate the desired 3D meshing format. This is usually done with a camera-based solution, but since we also have LIDAR (the FFI project Competence Buildup LIDAR), we can use both sensors to scan objects and then convert to the desired 3D meshing format.
Delivery	Objects and static environment in desired 3D-format.

The objective is to have accurate 3D-representation over the statical infrastructure at AstaZero to help its customers perform anything from pre-test execution and simulation with a representative model over the track. And if asked, have the capability to update the representations and/ or add dynamic objects that we have.

Table 2 Translation of work package 2 from the project application, Including work content, method, delivery, and objective.

WP 2	AR/VR Visualizer
Description of contents	Expand the possibilities to visualize ongoing and recorded tests using VR and AR. In real-time during a test, use AR or VR so that the test driver can see virtual objects as close to real-time as possible. Use VR to visualize real-time tests from a different location and to subsequently be able to analyze a test in a VR environment.
Method/approach (when relevant)	Start by creating a 3D mesh format over AstaZero and objects (AP1). Use commercial software and hardware to view that environment in VR, this also includes being able to switch positions in the VR environment. Implement the interface between AstaZero's test control system and simulation software (AP3). This allows all objects to send near-real-time information with their positions. The position update of all objects and coordinate system correction need

	to be done in this project for VR to be implemented. Purchase hardware that supports AR and VR, e.g., screen solutions and existing user interfaces in AR and VR. Implement the hardware in the car for real-time visualization for test drivers. Implement necessary software for injecting 3D objects into AR hardware. Create log files over the actual trajectories of objects from a physical test. Replay of this log file in the simulation software's environment. This is done by knowing which objects are used during the test (their dimensions) and how they have been driven (position data and time). Then each moving object in the simulation is fed with the saved position data over time. This enables measurement and verification of the margins between different objects and similar, which today is significantly harder to do during physical tests.
Delivery	Support for VR (Virtual Reality) and AR (Augmented Reality) for visualization during testing. VR support for post-test visualization, using log files.

The objective is to work toward visualizing the virtual objects that can exist in case of a mixed reality test which is something that is very likely to become more common in tomorrow's testing on proving ground, especially when the scenarios and number of objects that should be controlled during a test increases.

Table 3 Translation of work package 3 from the project application, Including work content, method, delivery, and objective.

WP 3	Connection to the test control system
Description of contents	Expand the existing interface between the test control system and simulation software to suit more simulation software. Apply a communication interface on the simulation side for real-time communication support. Communication interfaces include support for virtual injection and dynamic trajectories, developed in Chronos 2. Investigate current simulation software's real-time support. If this is missing, solutions for real-time support should be explored. Further develop the interface to support the streaming of sensor data from simulation to object.
Method/approach (when relevant)	(Application of knowledge taken from Chronos 2) From information sent from the test control system, an interface is defined that provides a simulation environment with the right number of objects and orientation. To achieve real-time communication between simulation and test control system, start by streaming position data to simulation for updates of the positions of the objects in the simulation environment. Investigate if it is close enough to real-time. If it is not near real-time, see if it can be solved in a

	quick and easy way, otherwise investigate other simulation software solutions. Explore streaming of sensor data regarding objects, evaluate real-time support.
Delivery	Communication interface between simulation tools, software, and the test control system.

The objective of this work package is to develop or implement communication interfaces between the test control system and simulation, this includes everything from pure simulation interfaces, mixed-, AR- and VR-reality interfaces and rigs.

Table 4 Translation of work package 4 from the project application, Including work content, method, delivery, and objective.

WP 4	OpenSCENARIO-generation
Description of contents	(Applying knowledge taken from the Simulation Scenario). Identify test cases that are of interesting to run fully autonomously. One of these test cases is manually translated into an OpenSCENARIO file. Test run the case in simulation and reality to test the systems. Ensure they have full support for each other and that the same results are obtained as in OpenSCENARIO but with AstaZero's systems. Investigate whether it is possible to directly create OpenSCENARIO files from a simulation environment that describes a test case with the current simulation software.
Method/approach (when relevant)	Start by going through AstaZero's library of test cases to find test cases of interest for automated testing. Then translate to OpenSCENARIO and run the case both in simulation and physical testing. Build the same test case in the simulation software and generate an OpenSCENARIO file. Analyze the result and then either improve or apply as part of the tool chain.
Delivery	The ability to create OpenSCENARIO files from the simulation software, which can supplement current test cases and Design Verification Methods (DVMs).

The objective is to be able to create OpenSCENARIO files and complement DVM: s and test methods AstaZero has today with them.

Table 5 Translation of work package 1 from the project application, Including work content, method, delivery and objective.

WP 5	Rig Development
Description of contents	Expand the possibilities of testing hardware and software in the rig. By integrating more simulation into the existing rig, the number of functional tests in the rig can be increased. This means that certain functions can be tested in the rig before real testing. This streamlines the current rig and gives the opportunity to close the loops in today's rig. It would then approach a Software-in-the-loop/Hardware-in-the-loop (SIL/HIL) rig. With the help of the pilot study "Verification of active safety systems in chassis dynamometer" and AstaZero's knowledge of existing rig, the existing rig can be developed and made more modular which can lead to increased use.
Method/approach (when relevant)	Use and apply parts of the learnings from the Vehicle-in-the-loop (VIL) pilot study. Investigate how to trick sensors in the rig. Apply functionality to trick the sensors that are reasonable to trick. Utilize simulation tools, simulation environment, and models to provide input and close the loop in the current rig to be able to do more functional testing.
Delivery	Develop a more HIL (Hardware-in-the-Loop)-like rig that can perform more functional testing for ADAS (Advanced Driver Assistance Systems) and make the current testing more efficient.

The objective is to increase AstaZero understanding and possibility to use different rigs such as HIL to increase the testing possibilities and efficiency.

6. Results and deliverables

This chapter describes the results and deliveries from the projected divided by work package. Starting from work package 1 and ending with work package 5.

WP 1 3D-Enviroments

Multiple different approaches were investigated to create or access 3D-envirvoments.

- Use AstaZero’s existing OpenDRIVE HD map, to create 3D-enviroment.
- Create 3D environment from camera with depth perception and IMU (Inertial measurement unit).

- Create 3D environment from combination of LiDAR (light detecting and ranging), Camera, IMU and GNSS (Global Navigation Satellite Systems) sensors.
- Create 3D environment based on schematics.
- Buy existing 3D environment or simulation software that has standard 3D-enviroment that can be built upon to fit the AstaZero proving ground.

1.1.1. 3D Model from OpenDRIVE Map

AstaZero used the existing HD map to create a 3D representation of the proving ground **Error! Reference source not found.**. With the help of in-house software and Blender (Blender 2023) multiple 3D models where created. Blender can export the different models to multiple different simulation software because of the many 3D formats it supports.

These 3D models of the infrastructure and complementary OpenDRIVE map were imported to CARLA (Carla 2023), to highlight the possibility to load such models and then use for testing or development in a simulation software. These models were used as a proof-of-concept in the rig development described in chapter WP 5 Rig .

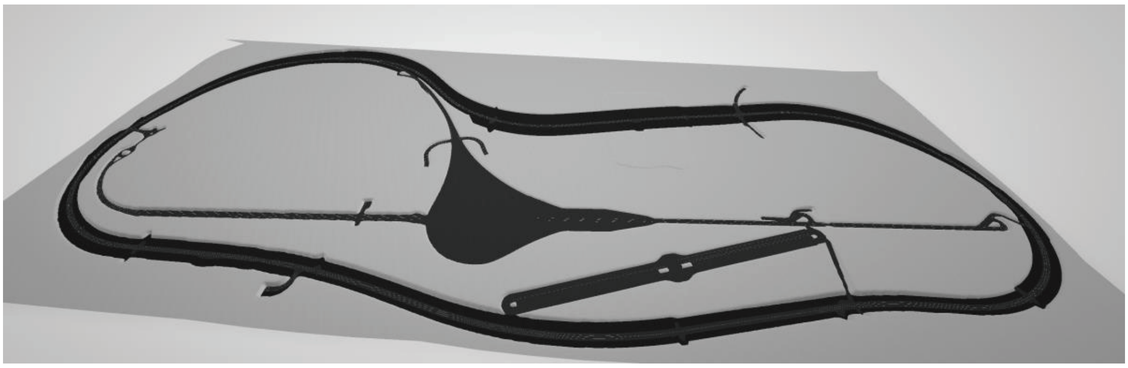


Figure 1 3D model of the AstaZero test track.

Other 3D-models were created later in the project with the help of the OpenDRIVE map over AstaZero proving ground **Error! Reference source not found.** and a commercial tool called RoadRunner (MathWorks 2023). This tool greatly simplifies the process of going from a OpenDRIVE representation to a 3D, Figure 3 shows a 3D model created in RoadRunner from the OpenDRIVE map, model compared to manually creating the 3D model by helping the user with keeping track of the geo-reference, having the possibility to load in multiple GIS (Geographic Information System) information entries and layering upon each other, and already containing a parser for many of the objects described in an OpenDRIVE. This means AstaZero doesn’t need to focus on creating all the static 3D models nor the mapping from OpenDRIVE to 3D models.

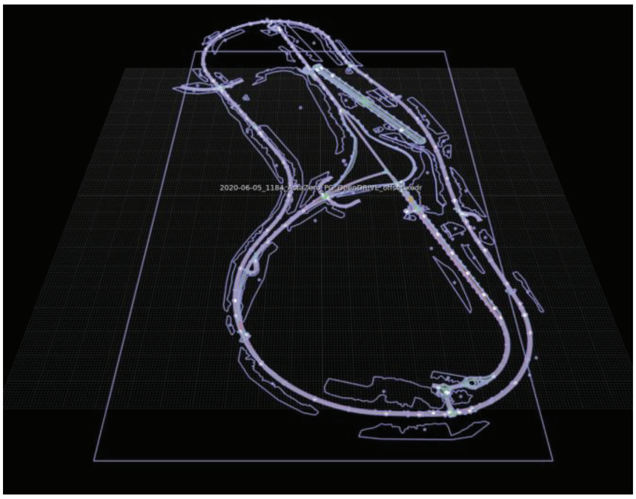


Figure 2 OpenDRIVE of the AstaZero test track visualized in RoadRunner.

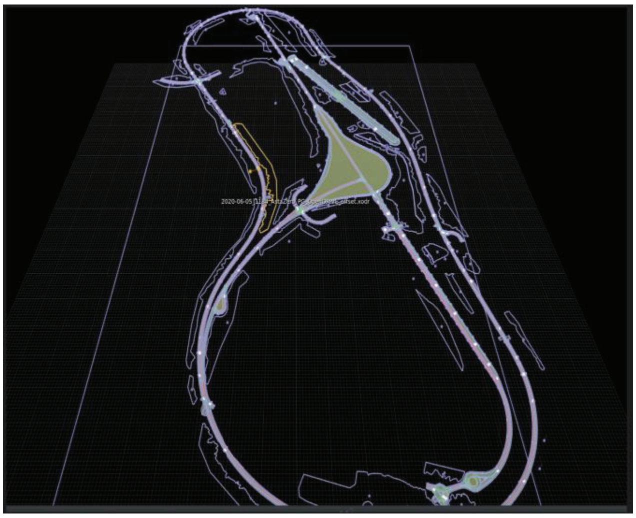


Figure 3 3D model based on OpenDRIVE of the AstaZero test track in RoadRunner.

The 3D model created with the help of RoadRunner were also imported to CARLA **Error! Reference source not found.** and small test drives were performed.

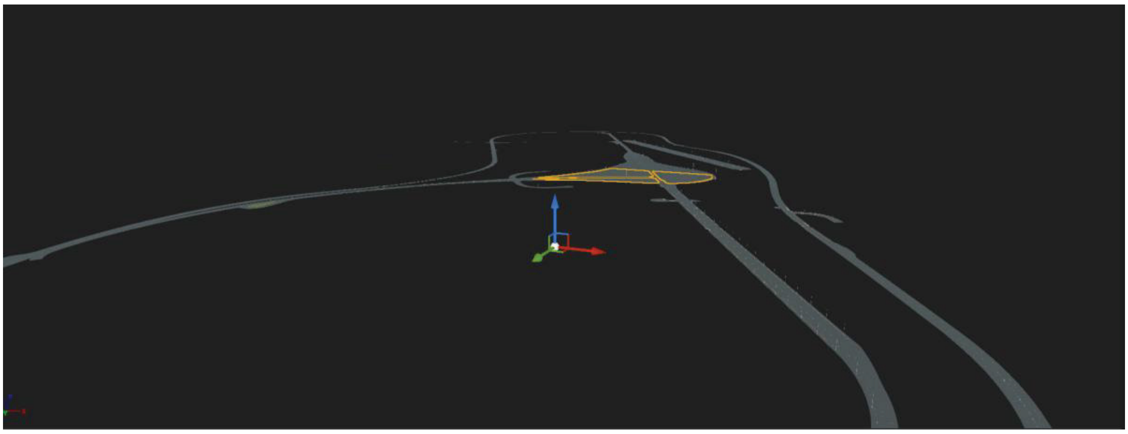


Figure 4 3D model of the AstaZero test track in CARLA.

1.1.2. 3D Model from Depth Camera

Another approach AstaZero explored was the creation of the static infrastructure as a 3D model using sensor data. A literature study and opensource code investigation were performed, the results of this study lead to a proof-of-concept utilizing Open3D GitHub library (Open3D 2021), ROS (ROS 2023) and a RealSense™ D455 (Intel u.d.) depth camera from Intel™, shown in Figure 5.

Figure 5 Intel RealSense D455, image taken from (Intel u.d.)

One of the problems with this approach was the depth vision and that this sensor setup can only see ~6m in depth and have a large measurement uncertainty the further away the object is from the camera. This led to 3D meshes that looked good from afar but when inspected more thoroughly multiple holes and discontinuities where observed. Offsets in the measurement and many vertices means the model will be difficult to render in most simulation software before a thorough cleanup.

This was due to measurement errors that occurs when trying to scan large surfaces or objects. In the proof-of-concept, a room of approximately 25 m^2 with different objects were scanned and a 3D model was created that show the problem discussed above. The errors arose from the fact that the RealSense™ D455 depth camera is designed for indoor robotic applications and not to track objects outside that are far away. It can still be used to scan specific objects that are not too large where the tracking algorithm does not have a problem calculating the cameras position in relation to the object that is being measured. When a smaller object was scanned, similar result was acquired as in Open3Ds example.

1.1.3. 3D Model from Combination of LiDAR, Camera, IMU, and GNSS Sensors

Another concept is to combine camera, LiDAR, IMU and GNSS that are made for outdoor usage and utilizing the same technical approach and Open3D to make the 3D models. This should result in less measurement errors when building the model due to higher end sensors. This is one of the reasons why AstaZero is now working on such a sensor platform.

1.1.4. 3D model Based on Schematics

Regarding creating 3D-models based on schematics, whenever they exist, and are detailed and accurate enough, such schematics (which are often in some CAD software) should be used. With the help of tools like Blender or Autodesk (Autodesk 2023) these kinds of schematics can often be exported to a 3D-model format that a simulation engine can use.

1.1.5. 3D models by Purchasing

When it comes to buying 3D models, this is also a good approach when looking for specific objects that are common, mainly because it is cost efficient. So often a look at marketplaces such as Unity (Unity 2023) or Unreal (Unreal Engine 2023) is a good start. When this becomes difficult is when the object that is needed is very custom, specific, or secret, which is common when it comes to autonomous vehicle design, testing and development.

WP2 AR/VR Visualizer

This section describes the work AstaZero performed within the AR and VR applications, visualizing different injected objects and data. This shows the possibilities in the vehicle for this technology and how it in the future can be used to monitor objects on the proving ground.

An AR proof-of-concept was developed in this work package. With the help of one of the interfaces developed in WP 3 Connection to the , real time information about test objects positions were streamed to an android tablet that was moving in the object under test augmenting the reality. Figure 6 shows a simplistic architecture of how that application was implemented.

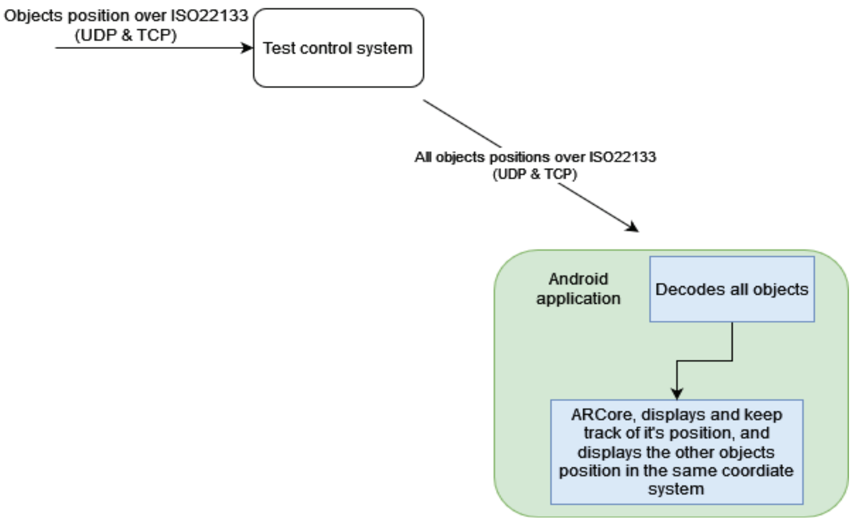


Figure 6 Shows the simplified AR application architecture.

The AR android tablet display during one of AstaZeros development tests are shown in Figure 7. The figure shows a snapshot of the android tablet display, where one completely simulated object can be seen (the black car) and a AstaZero radio-controlled car that has an augmented 3D car on-top of it. This shows the real time application works with multiple objects and that the mapping of the objects is in the same coordinate system which is anchored to the android tablets camera coordinate system frame.

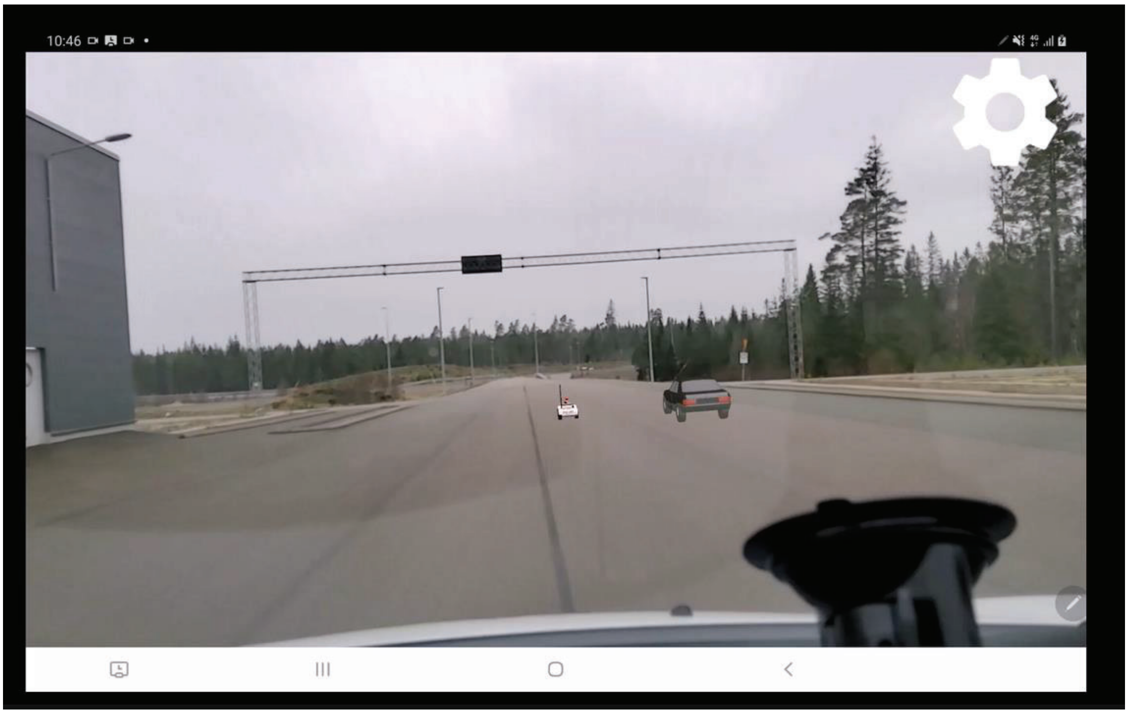


Figure 7 Screenshot from the AR tablet

After calibration, this AR proof-of-concept shows that it is possible to perform this kind of mixed reality test for either HMI (Human machine interface) tests or to replicate scenarios that would be too dangerous to do without the help of combining simulated objects and real objects in close to real time. A video of this system in real time was shown in CNN Tomorrow Transformed (INRIX u.d.).

The AR application is an android application that receives positioning information of all the objects over the ISO22133 communication interface from the test control system. With the help of the object position information transmitted from the test control server, it anchors itself to the object it is placed inside and then starts calculations by mapping its movement in the environment and its camera position/frame in relation to the other objects position it receives. Then it displays the virtual Objects in the camera feed based on these calculations.

The limitation with the android app was that sometimes the mapping of the camera frame in the vehicle lost its position, which meant it had to be recalibrated. Also, the fact that this was an android tablet mounted below the car window looking forward means that the immersiveness of the driver is low, making it difficult to perform real HMI studies, and the freedom to look right and left while driving is very difficult.

Therefore, a market study was performed on AR and VR headsets that could be used to replace the android tablet. The AR/VR headset that showed best potential and possibility to remove the drawbacks of the android tablet looked to be VARJO XR-3, Figure 8. A pair of these were bought and some implementations were started in the project to see how they could be used together with AstaZeros research car and control system.

Figure 8 Varjo XR-3 (VARJO u.d.)

The reason a lot of effort was not put on VR by itself was due to a bachelor thesis (Eriksson 2021) performed parallel with this project at AstaZero,already started this work. Also, during the time of the project the implementation of VR were getting much easier, due to most gaming engines that can be used for simulation now support VR out of the box. Making it a lot easier to apply VR when needed.

WP 3 Connection to the Test Control System

This section describes the results the work performed in WP 3 how simulation, AR,VR and MR and other objects is connected to the control system,

The android tablet developed in WP2 AR/VR Visualizer was connected to the test control system with the help of a UDP (User Datagram Protocol) and TCP (Transmission Control Protocol) connection compliant to ISO22133 (ISO 2023) where it received all the object information that the test control system knew about. This was done by reusing the MONR and OSEM message in ISO22133. This meant that new decoders were implemented in Java in the Android tablet application for it to read the messages. Those two message types included the bare minimum to be able to get the android application working.

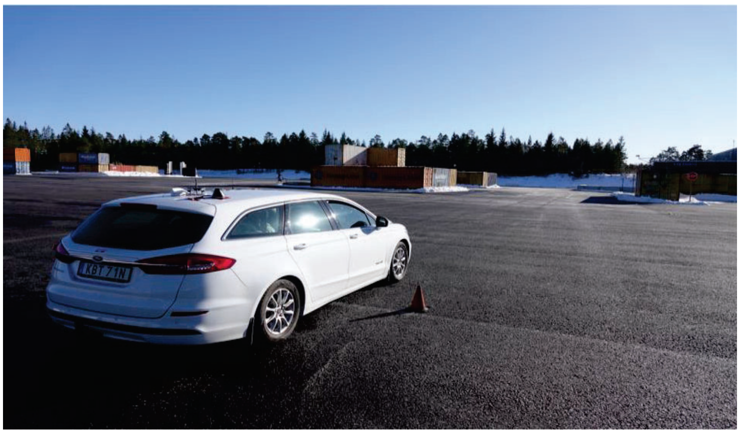
During the project we soon realization that every time the test control system was connected to a new simulation tool or similar, there was a high chance for the need to write new encoders or decoders of the ISO22133 standard due to simulation tools only allowing specific programming languages, which is not always C or C++ which AstaZeros (AstaZero u.d.)encoder and decoder together with AstaZero's ISOobject (AstaZero u.d.) is written in.

The solution to this problem was first implemented in this work package by using swig (Swig-developer u.d.) Swig is a Simplified wrapper and Interface generator which helps. wrap C and/or C++ code to many programming languages.

The methodology of using swig has been very successful within the company and have helped us centralize our code base, the same methodology is used when AstaZero is connecting any new object to the test control center that is not supporting C and/or C++. This have enabled AstaZero to put more focus on increasing functionality and usability of the ISO22133 and ISO object code base instead of writing interfaces.

The C and C++ code for ISO22133 was wrapped for python to quickly implement the ISO22133 standard towards CARLA. This meant that now CARLA could report one of its objects in the simulation the same way as an ordinary ISO22133 test object to the control center during a test. This was used to stream real time information from a simulated object in CARLA to the test control center to display virtual objects, and to also send other objects information to CARLA. This enables other objects or ego-vehicle to be populated on the simulated test track in the CARLA environment. The RCMM and DCMM messages in ISO22133 was also written in this project to let a simulation software control an actual vehicle on the test track. A proof-of-concept of this application will be shown in WP 5 Rig .

Except for the ISO22133 communication interface AstaZero has also explored the OSI (Open Simulation Interface) from ASAM standard. This work package has helped implement OSI support in AstaZeros CARLA python interface, AstaZero's test vehicle, Ford Mondeo with a dataspeed solution (dataspeed u.d.) Figur 9 and AstaZeros test control system. This have enabled AstaZero to stream real time sensor information and position of different objects from CARLA to vehicle under test. This was displayed at a demo in the spring of 2023 on AstaZero's proving ground, where all communication that displayed virtual objects, or sensor data, was done through the OSI interface.



Figur 9 Shows AstaZero development vehicle.

WP 4 OpenSCENARIO Generation

AstaZero have a DVM and test case database from previous work done at AstaZero, with approximately 400 tests. This test database was explored in the beginning of this work package and analyzed.

Around 200 of these where selected to be investigated if they were a unique scenario. The result from the 200 test was that approximately 50 of them where unique scenarios that could be translated to OpenSCENARIO. After the identification AstaZero picked a handful of them and developed a methodology to create the OpenSCENARIO file from test specification. This included using the pyoscx scenario generator [(Mikael Andersson u.d.)]. Which enabled AstaZero to faster create the scenario file and learn its structure. Some of these scenario files were later attached to the test case database.

The scenarios were executed in esmini (developers u.d.) and CARLA. Due to the standard being open the implementation differed a little and they were not at once executable in both simulation software. This means that there were, when this was performed, some more work to be done to harmonize the open standard.

At the same time AstaZero looked outwards for existing and open scenario databases that can be used to increase the test possibility in an efficient manner in simulation and on proving ground. AstaZero now have access to one such database.

Example of one of the scenarios exported and OpenSCENARIO created can be seen in Figure 10 and run in esmini in image Figure 11 & Figure 12.

Target vehicle 1 (T1) and 2 (T2) drives in the same lane with a set distance between them. Subject vehicle approaches from behind with ACC activated and follows target T1. Target T1 changes lane while target T2 decreases its speed. Subject vehicle adapts to target T2

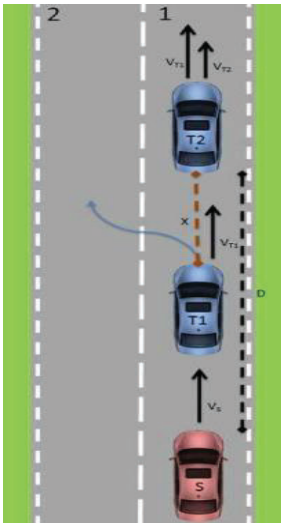


Figure 10 Shows a test case, from AstaZero database.

The work here has also included investigating the esmini code base to see if it was suitable for AstaZeros test control system for understanding and help decode such scenarios to iso22133.

The base knowledge built in this work package has helped AstaZero in other FFI project such as FFI ASCETISM (reference number 2020-05137), FFI EVIDENT (reference number 2021-05043) and FFI SAFRAN (reference number 2021-05042).

Towards the end of this project the OpenSCENARIO 2 standard was released which is a standard this project decided to not investigate in detail or create scenarios in.

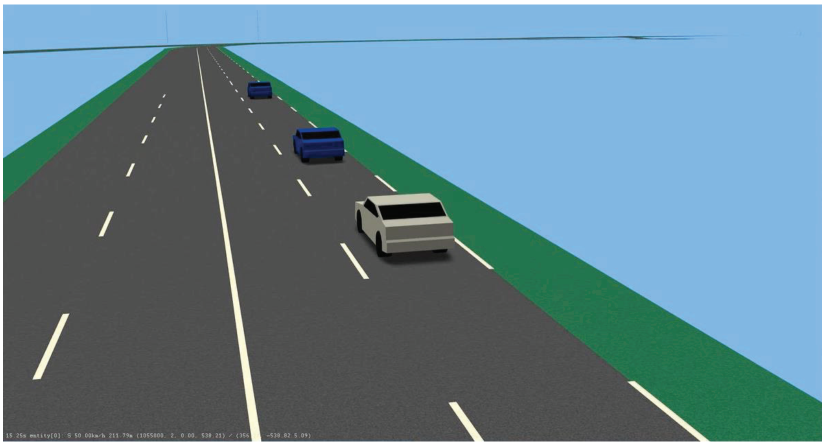


Figure 11 Beginning of the OpenSCENARIO executed in esmini.

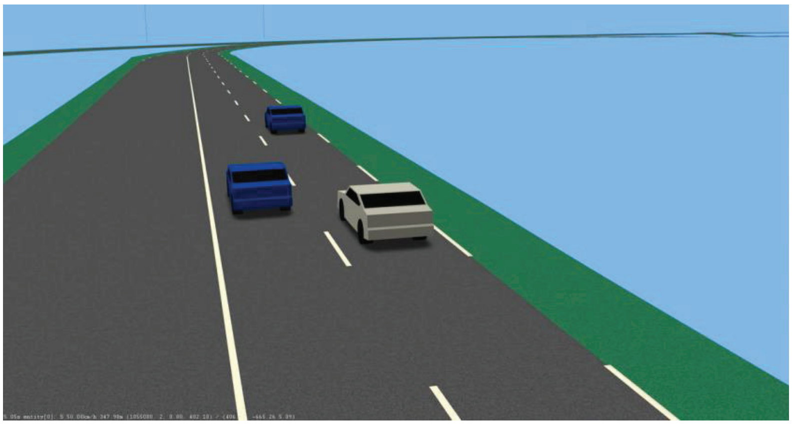


Figure 12 Towards the end of the OpenSCENARIO file executed in esmini.

WP 5 Rig Development

In this work packages AstaZero investigated the possibility to use HIL rigs to complement and/or increase the amount of testing that can be performed on a ADAS vehicle today from a third-party perspective without too much knowledge about the system itself.

A proof-of-concept was developed where a projector was displaying the 3D-modell described in WP 1 3D-Enviroments over AstaZeros proving ground. This was shown in front of one of our cars with a camera based ADAS system on it. After some trial-and-error parts of the system activated, one of the systems that triggered was traffic sign recognition which recognized different speed limit signs placed in the 3D-enviroment, and the lane keeping aid system. Figure 13 shows the projector screen in front of the car.

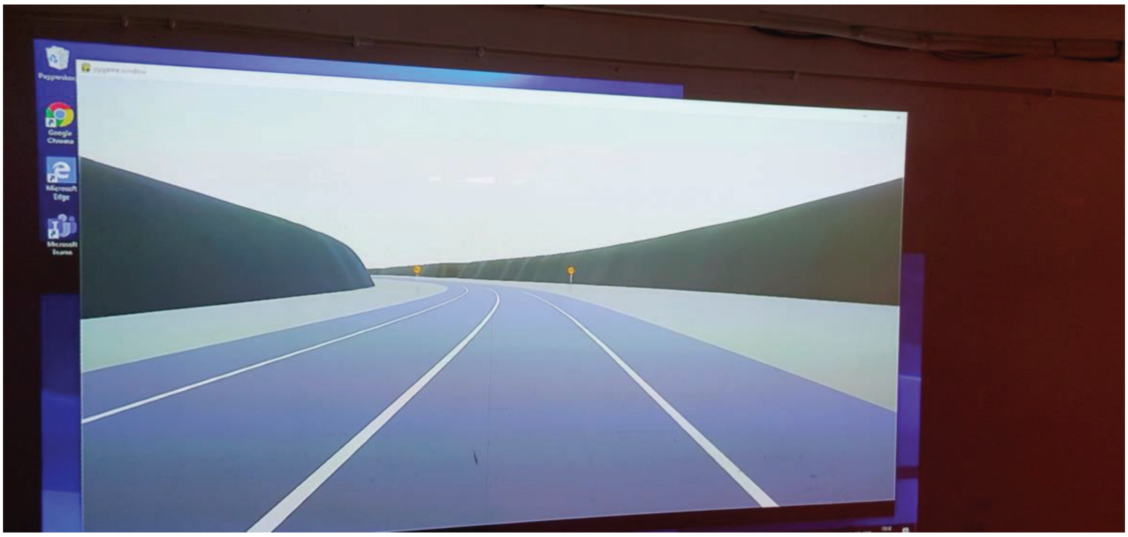


Figure 13 Projector screen in front of a car.

From this result AstaZero developed another version of a VIL where AstaZero use the test control center to send data from a remote location (intent to be a cloud solution with simulated sensor data in the future) to a car operating on the proving ground. Figure 14 show a rough schematic of how the procedure works. Here image data from a simulation was displayed in front of a ADAS system hardware and then sent the instruction through ISO22133 in this case (TCP & UDP) to the control center that then gave steering commands to the actual car on the track, so it was driving on the track within virtual lanes.

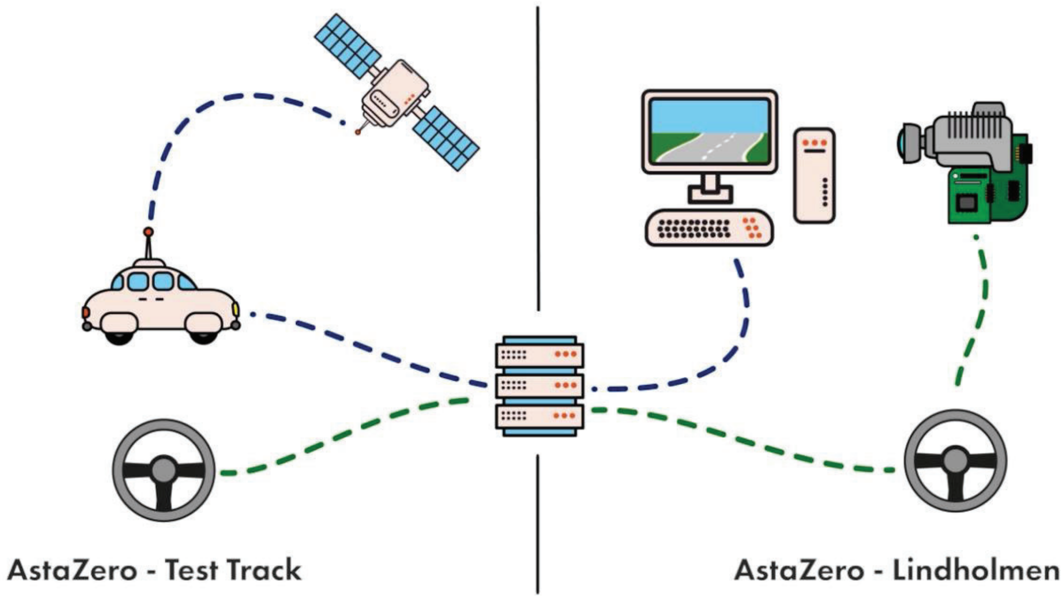


Figure 14 Describes the overview of the systems and their connection, for the VIL proof-of-concept.

The issue here was the delay this incurred, it varied from 25 ms to over 100 ms which makes this approach difficult, especially the irregularity. But if the simulation node was put on the edge and made use of 5G there is a high feasibility that this would work.

The work here was later expanded upon and some of it was reused. In the ESTAT demo described in Publications, where a car was put on a dynamo, a projector and screen put in front of it and then a radar target moving towards the car. This did activate the autonomous emergency braking system. This shows that there is a possibility for an independent 3:rde party test and validation organization to test these systems without having to rely on the manufacturer.

Overall, the goals setup in this project have been reached, AstaZero has improved its knowledge within the field of simulation and virtual validation and testing. There are now many projects continuing the work started in this project and a number of projects has also been going on during the same time frame that has used the knowledge gained here to faster deliver results in other projects. Such as FFI EVIDENT (reference 2021-05043 number) and FFI SAFRAN (reference number 2021-05042) and FFI DIGITAL VEHICLE TESTING AT ASTAZERO (reference number 2022-01648).

7. Dissemination and Publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field		
Be passed on to other advanced technological development projects	X	Results will be used in the following research projects. FFI EVIDENT, FFI SAFRAN, FFI DIGITAL VEHICLE TESTING AT ASTAZERO
Be passed on to product development projects	X	Test control system and correlation between physical and simulated testing.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

7.2 Publications

Results from the project were showcased in the TV program Tomorrow Transformed (INRIX u.d.) on January 11, 2020, which is run by CNN. AstaZero's test track was presented, along with various technologies that AstaZero has developed. An example was a demo of an application that uses "Augmented Reality" that was developed in this project. Where communication from the test control system was used to show where the virtual objects is in relation to the android tablet with the AR application.

Some of the system, proof-of-concepts, developed in this project where later used in (RISE Research Institutes of Sweden u.d.) to stimulate different sensors on a car to activate the cars AEB system.

15 of March 2023 AstaZero gave a demonstration (AstaZero u.d.) many results from this project were displayed everything from ISO22133 object integration, OSI integration to simulation over 4G network using CARLA and virtual sensor information being used to activate home developed ADAS functions. For usage of esmini and OpenSCENARIO generation with a corresponding 3D-enviroment and OpenDRIVE map.

8. Conclusions and Future Research

The 3D-generation work package (WP1) created methodologies and multiple 3D-models in different formats over the AstaZero proving ground, as the objective of that work package stated. These models have also been used in other projects and tools and will continue to be used in new projects that will continue the development and research work.

Future research within this domain could be focus on synthetic data generation on the proving ground to perform more testing on ADAS and AD system, especially robustness and repeatability. Another research area would be applying digital twins to create and maintain these and other cyber physical systems models. Or automatically create these 3D models by combining multiple sensors and machine learning models.

The AR and VR (WP2) work package also fulfilled its objective, the AR application makes it possible for test engineers to see virtual objects during test activities at the track. The VR implementation was also covered but in a bachelor’s thesis outside of this project, therefore more effort was not put on the VR application.

Future research within this domain would be a more immersive AR implementation during tests on the proving ground. This would make it easier to perform more HMI studies on different system everything from display systems to ADAS and AD system interaction, while driving on the proving ground.

WP 3 took care of the system integration and communication needed to connect simulations AstaZero performed to the test control system for usage on the proving ground as the objective stated.

Interesting future research topics would be the application of 5G communication to distribute the sensor data, especially from simulation. This would lower the delay and increase the bandwidth, which is one of the limitations today, especially if you're not on the edge node. Also connecting more objects and sensors to the simulation environment in real-time to be able to create a real digital twin over cyber physical systems that updates in real time where models can be tweaked and improve over time with the data collected.

The OpenSCENARIO work package (WP4) increased the knowledge of creating OpenSCENARIO 1 scenario files as the objective stated and created a methodology by finding suitable tools to utilize. An investigation of how many inhouse scenario files AstaZero have was performed and the possibility to create a bigger such database was achieved. AstaZero also looked at outside scenario data sources with the idea of using and contribute to these data sources in the future.

WP5 developed multiple rig applications that shows the potential to use different hardware rigs not only to verify signal output from ECUs (electronic control units) and software version but also the possibility to use them to test simple functionality.

Future research in this area should build upon the sensor stimulus and inject simulated data in ECUs in either complete software (SIL, software in the loop) or HIL/VIL (Vehicle in the loop) system. This is due to it being one of the few ways a third-party independent test and validation organization can test all the different parameters a higher level ADAS or AD system need to be tested through.

9. Participating Parties and Contact Persons

The purpose of this project has been to enhance AstaZero's competence and capability, and there are no other parties involved in the project. Adam Eriksson serves as project manager and work package leader for all the work packages.

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