Augmented Reality Simulation for Testing Advanced Driver Assistance Systems in Future Automotive Vehicles

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***Abstract*—To take advantage of Advanced Driver Assistance Systems (ADAS) testing in simulation and reality, this paper presents a new approach to using Augmented Reality (AR) in future automotive vehicles to test ADAS. Our procedure creates a connection between simulation and reality and should enable a faster development process for ADAS tests and future mobility solutions, which will become increasingly complex in the future. Complex automotive environmental conditions, such as high vehicle speed and fewer possible orientation points on an urban test track compared to using AR applications inside a building, require high computing power for our approach. Using Image Segmentation (IS), Artificial Intelligence (AI) for object recognition and visual Simultaneous Localization and Mapping (vSLAM), a three-dimensional model with accurate information about the urban test site is generated. The use of AI and IS aims to significantly improve performance, such as calculation speed and accuracy for AR applications in complex automobiles.**

***Index Terms*—Artificial Intelligence, Augmented Reality, Advanced Driver Assistance Systems, Visual Simultaneous Localization and Mapping.**

I. INTRODUCTION

Advanced Driver Assistance Systems (ADAS) are more and more spread in current and future cars because they are increasing vehicle safety by recognizing road signs, keeping the car in its lane, or regulating the speed adaptively. These complex systems go through an extensive test phase, resulting in the potential for optimization in terms of quality, reproducibility, and costs. Due to the increasing complexity of vehicle communication and the rising demands on these systems in terms of reliability to function safely even in a complex environment and to support the driver, test scenarios for ADAS are constantly being further developed to meet higher requirements. The European New Car Assessment Program (Euro NCAP) has included a series of new safety tests for ADAS in its program and has drawn up a roadmap up to the year 2025 [1] [2].

Current testing methods of ADAS can be divided into simulation and reality. The core idea of using simulation is to transfer the behavior of the vehicle to the virtual test drives as realistically as possible. The approach of using simulation aims to use the advantages like reproducibility, flexibility, and cost reduction. In this way, the specifications and solutions derived from this should be able to be tested and evaluated at an early stage of the development process. Using suitable simulation methods enables the efficient design, development, and application of vehicles and vehicle components. However, simulation cannot yet replace real test drives in all respects. Due to the complex physical conditions under which a vehicle is handed over during ADAS tests, real test drives are still required for the current status. For example, weather, road surface conditions, and other influencing parameters play a crucial role in the evaluation of ADAS road tests [3] [4].

However, the test and evaluation effort correlate with the complexity of an ADAS. The more complex the system, the greater the testing effort. The robustness, functional safety, and reliability of the ADAS must be proven in increasingly dynamic, complex, and chaotic traffic situations. This also includes the interaction with different road users, each with their natural movements, such as, e.g., the interaction of road users with each other. Therefore, new and efficient test methods are required to pave the way for future ADAS [5]. This paper describes the usage of Augmented Reality (AR) for testing camera-based Advanced Driver Assistance Systems. In Section II a description of ADAS basics is presented. Section III describes the current methods used for testing ADASs. Section IV, shows a possible usage of Augmented Reality and its challenges. The paper is concluded by Section V, where the research, results, and lessons learned are discussed.

II. ADVANCED DRIVER ASSISTANCE SYSTEMS

ADAS supports the driver when operating a vehicle. Depending on the type, they ensure more driving comfort, increase safety, reduce energy consumption or enable more efficient traffic flow. The systems record the driving situation via sensors, process the collected information with powerful computers, and give the driver optical, acoustic, or haptic feedback. In some cases, they intervene automatically, semi-autonomously, or autonomously in the control and operation of the vehicle, for instance by accelerating, braking, signaling, or steering. These can extend to fully autonomous driving. The main requirements for ADAS are fast data processing in almost real-time and high system reliability [6] [7]. A growing number of environment sensors, such as radar, camera, ultrasonic, and lidar sensors enable the use of ADAS in modern vehicles and related functions for autonomous driving. At the same time, each sensor is severely limited in its scope and cannot provide all of the information about the vehicle's surroundings that is required for safety functions. Only the combination of data from different sensors (sensorfusion) results in a complete environment model, a basic requirement for the reliability and safety of driver assistance systems and autonomous driving [8].

III. TESTING OF ADVANCED DRIVER ASSISTANCE SYSTEMS

Simulated test procedures during the development process, as well as real test procedures, are used to evaluate the functionality of individual ADAS sensors and their joint interaction in ADAS-relevant scenarios. While all test drive components remain virtual in the first concept phase, virtual components are successively exchanged for associated real test elements over the various integration stages in the course of development. Up to entirely real test drives with real drivers and road users, the simulation components have entirely given way to reality [9].

A. Testing Advanced Driver Assistance Systems in Simulation

The guiding principle of the virtual test drive is to transfer the real test drive to the virtual world as realistically as possible. The aim is to use the characteristic strengths of simulation in terms of reproducibility, flexibility, and cost reduction and to establish a test and evaluation option for the specifications and solutions derived from this early on in the vehicle development process. Using suitable simulation methods enables vehicles and vehicle components to be designed, developed, and used more efficiently. They serve as a bridge and shorten the time until real vehicle prototypes are available. With real test drives and the reliability of real test results as a template, Using simulation techniques is an optimization task in which the modeling, parameterization, and simulation effort must be matched to the efficiency achieved. The methods used for this approach mainly come from the repertoire of integrated mechatronic system development. Here, the methods: Model in the Loop (MiL), Software in the Loop (SiL), Hardware in the Loop (HiL), and Vehicle in the Loop (ViL) come into question [3].

B. Testing Advanced Driver Assistance Systems in Reality

While vehicle dynamics control systems can still be validated in real driving tests with great effort, despite all their complexity and variety, this is no longer economically viable for ADAS today due to the complex system, the complexity of the test cases, and the necessary scope of the tests. Even if the tests are supposed to be performed in the same way, in practice it is impossible to perform the tests under the same conditions due to the many potential and sometimes unknown or ignored influences. The reproducibility of the results is therefore not given because on the one hand the functionally relevant features can contain the necessary interaction of several road users and on the other hand a complex interaction of a general nature can be subject to conditions, such as low glare, simultaneous sun, and reflection on a wet road surface at a specific angle. Current ADAS functions access information about the environment, sometimes collected from multiple sensors with different functions and processed into a representation of the environment [4] [10].

We use the Euro NCAP as the standard. That is a Europe-wide standardized test procedure for ADAS with real driving tests. The focus is on the behavior and reaction of the vehicle in safety-critical situations. In simulated dangerous circumstances, dummies in the form of vehicles driving ahead, pedestrians, and cyclists are used to test the functionality of ADAS systems. In a further step, the reaction time of the hazard message for the driver is evaluated. Due to the constantly increasing traffic safety, the test procedures of Euro NCAP will also contain more complex test scenarios in the future. Therefore, the roadmap up to 2025 also includes other road users, such as scooters, motorcycles, and wild animals to increase road user safety [11]. An Autonomous Emergency Braking (AEB) test scenario in which a pedestrian (child or adult as a dummy) crosses the street in which a car is turning is shown in Figure 1. The test vehicle must detect the pedestrian and avoid personal injury or property damage by braking [12].

C. Combining Virtual and Real Testing

To enable the testing of camera-based assistance systems in real environments earlier in the development phase and thus increase the quality of the systems, the use of AR as a link

Fig. 1. Pedestrian is crossing a road in which a car is turning [12]

between virtual and real testing lends itself to this. Using AR to test camera-based systems combines the advantages of a virtual environment and these of the real world: Reproducible, complex scenes with realistic environmental conditions. AR thus makes it possible to dispense with test dummies or second vehicles including drivers even in the initial phases of testing. This reduces the costs of the tests and increases the safety of the test engineers. The combination of different test situations is also possible: The display of several vehicles, lane markings, and road signs allow the simultaneous testing of all camera-based driver assistance systems. The unlimited variety of test scenarios allows a significant increase in the depth of testing at an early stage of development. That increases the quality of the testing and thus of the overall system. In 2010, a Swedish team led by Jonas Nilsson presented a software framework at a conference that used AR to evaluate a pedestrian detection system. The framework was able to augment the images from the vehicle camera to include a walking pedestrian. The resulting detection system results were comparable to test results obtained with real obstacles. As summarized in this paper, deeper investigations are needed to further advance an AR test system [20]. In the following, an AR-approach will be discussed.

IV. AUGMENTED REALITY SIMULATION IN ADVANCED DRIVER ASSISTANCE SYSTEMS

Different criteria are required for the use of AR in testing automotive ADAS than for conventional AR applications, such as on a smartphone. This section describes the test criteria for this approach.

A. Augmented Reality for regular Applications

According to Azuma's proposal, AR can be defined as a combination of three fundamental characteristics: the combination of real and virtual worlds and the precise three-dimensional registration of real and virtual objects, both in a real-time interactive environment [13]. The basic principle of AR is mainly known from the mobile game Pokémon Go [17]. Within this game, users can interact with digital creatures through their smartphones. These creatures are placed virtually in the user's environment. One such AR application is shown in Figure 2. Figure 2 shows also a self-created AR-App for demonstrating a possible scenery with traffic signs and a pedestrian. The three parts of the algorithms behind AR are image analysis, 3D modeling, and augmentation.

Fig. 2. Pokémon Go-App on the left side of the figure [17] and a self-created Augmented Reality application showing a possible scenery on the right side of the figure

Image analysis serves to identify points or areas of interest within the given image. Feature detection, such as corner detection is often used for this step [14]. A three-dimensional model of the environment is created using the results of the image analysis. The types of algorithms used for this step vary depending on the type of AR application. Simultaneous Localization and Mapping (SLAM) or Structure-of-Motion (SfM) algorithms are often used for AR in unknown locations [14]. The augmentation is based on the results of 3D modelling. The scene model is typically provided as a positional description of a plane or coordinate system that represents the real world [14]. With this information, a virtual object can be placed on the plane or in the coordinate system with appropriate characteristics, such as size and orientation. After object placement, the virtual content is combined with the real image [14].

There are different versions of applications for AR. These applications are very diverse in their fields, from the use of AR in psychology [13] to use in hospital operating rooms [14] to mobile games [14] to military applications [14]. What all these apps have in common is that human reality is expanded. With humans as users of AR, there are implications for the application. One is that, in most cases, the human user is forgiving of not accurately placed virtual objects, if the error lies within a small margin. In addition, the speed of human movement, and therefore the distance covered in a given time, is limited. Because of these limitations, localization, mapping, object placement, and runtime requirements are not as strict and demanding as in the automotive environment given in this paper.

B. Approach for Using Augmented Reality in Advanced Driver Assistance Systems

With a focus on the camera-based ADAS sensors, the area around the test field is recorded, as shown in Figure 3. The path between the sensor fusion module and the Electronic Control Unit for Advanced Driver Assistance Systems (ADAS-ECU), which causes the vehicle to intervene, for example by braking, has to be disrupted and a new path has to be found through the Augmented Reality Electronic Control Unit (AR-ECU). Within the AR-ECU, the captured environmental data is augmented with virtual objects, such as traffic signs or lane markings. The aim here, is a realistic and consistent behavior of the ADAS-ECU as in real object detection. For the final augmentation of the virtual objects on the real image of the sensor, a detailed 3D environment of the test environment must first be created. For this purpose, a visual Simultaneous Localization and Mapping (vSLAM) approach is chosen. The vSLAM method uses only visual inputs to perform localization and mapping. That means no vehicle sensors other than the vehicle's camera system are needed to create a 3D model of the environment, making this approach more flexible than lidar, radar, and ultrasonic. The vSLAM algorithm framework mainly consists of three basic modules: initialization, tracking, and mapping, and two additional modules: relocation and global map optimization (including loop closure) [15]. Several approaches with the vSLAM algorithm are available for using vSLAM in automotive vehicles and the associated properties, such as fast scene changes and low environmental textures, which can be found in [16]. Based on [16], various vSLAM approaches are compared in terms of accuracy and robustness, among other things.

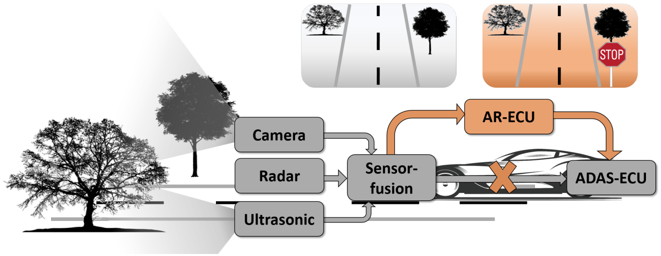

Fig. 3. Our approach for using Augmented Reality in Advanced Driver Assistance Systems

C. Oriented FAST and Rotated BRIEF (ORB) as approach for visual Simultaneous Localization and Mapping

The approach "Oriented Features from accelerated Segment Test (FAST) and Rotated Binary Robust Independent Elementary Features (BRIEF) (ORB)-SLAM" was first introduced in 2015 and seems to be state-of-the-art because it has higher accuracy than comparable SLAM algorithms [16]. Here, ORB-SLAM represents a complete SLAM system for monocular, stereo, and red-green-blue-depth (RGBD) cameras. The system works in real-time and achieves remarkable results in terms of accuracy and robustness in a variety of different environments. ORB-SLAM is used for indoor sequences, drones, and cars driving through a city. The ORB-SLAM consists of three parallel main threads: Tracking, Local Mapping, and Loop Closure. A fourth thread can be created to run the Bundle Adjustment (BA) after a closed loop. This algorithm is a feature-based approach that represents the detected feature points in a three-dimensional MapPoint [16]. Figure 4 shows a MapPoint on the left side created from internally acquired image sequences. Detected Feature Points that are used creating the MapPoint are displayed on the right side of the figure.

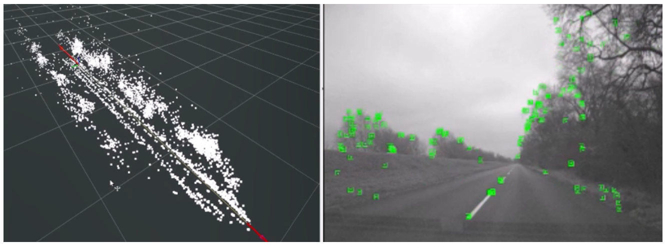

Fig. 4. Selfcreated MapPoint on the left side of the figure and the detected feature points (green rectangles) on the right side of the figure

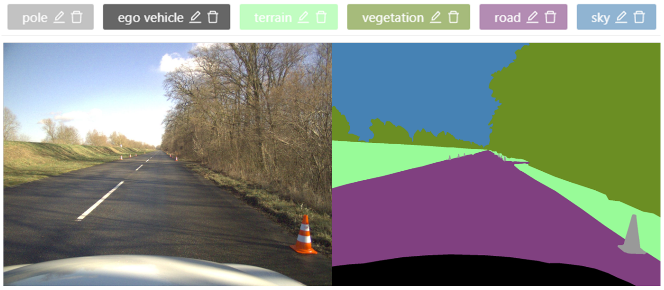

Fig. 5. Original image on the left side of the figure and the recognized objects using Image Segmentation (Pole, Ego Vehicle (Hood), Terrain, Vegetation, Road and Sky) on the right side of the figure

The increase in accuracy of the MapPoint created by ORB-SLAM with correspondingly recognized objects and surfaces is made possible by using IS and AI. Figure 5 shows the object detection. On the left is the original picture of the front view of the car. Since the Euro NCAP tests are conducted in dedicated test areas with low texture and therefore less information about the environment (see Figure 1), the recognized classes for our approach are pylons, own vehicle (hood), terrain, vegetation, road, and sky. More classes should be added in the further project progress. This means deriving plans from MapPoint, recognizing the road surface, and realistically enlarging objects on the virtual map. Another focus of this work is the realism of magnification, such as occlusion, reflection, and shadows. The vSLAM location mode is used to augment individual camera pixels to present the vehicle with a real-life hazard situation.

D. Advantages of our Approach

Our approach will combine the specific advantages of testing in simulation (reproducibility, flexibility and cost reduction) and reality (vehicle and environment complexity) and thus represent a link between these test methods. It should make it possible to test more complex scenarios and thus increase the safety of road users. The lane crossing enables, for example, a lane departure warning system to be tested independently of the test site. Scenarios, such as the appearance of temporary lane markings or missing sections, can be tested in the same test area. Narrowing and widening of lanes can be displayed, as well as international differences between lane markings. Vehicles driving ahead can be superimposed on the camera image to test traffic jam assistants. In the first test phase, there is no need for a second vehicle including driver, which reduces test costs and increases safety for test engineers. In addition, test cases with traffic signs, pedestrians and cyclists can be added quickly and situationally. It is also possible to combine different test situations. The unlimited variety of test scenarios enables a significant increase in test depth at an early stage of development. This increases the quality of the tests and thus of the system in general. Due to the increasing number of ADAS and the constant development towards autonomous driving, the application area of the software program can be expanded as desired.

E. Challenges for our Approach

Various advances and improvements in terms of accuracy, robustness, etc. can be found in later developments based on this ORB-SLAM approach [16]. While ORB-SLAM's performance is impressive on well-structured sequences, error conditions can occur on poorly-structured sequences, such as Euro NCAP test scenarios or when feature points temporarily disappear, for example due to motion blur [16]. In addition to accuracy, the execution time of the global algorithm is also of great importance. Camera systems in automotive vehicles today work with a frame rate of 30 to 60 frames per second [fps] [7]. For a successful evaluation of ADAS test scenarios, the AR system must be able to orientate itself very precisely in the environment [16]. One cause is the missing feedback about the impact intensity of test dummies when crashing them. Because of this, it is necessary to know the exact position of the car on the test track in order to calculate the intensity of the impact based on the braking distance. Using Euro NCAP test scenarios, speeds up to 130 km/h, which is equal to 36.111 m/s, are proven [11]. The algorithm must have a faster execution time compared to the speed of the camera system. The distance d that the vehicle covers within one frame at a given speed and frame rate can be calculated. At a speed of 130 km/h and using a camera framerate of 30 fps, the vehicle travels

$$d = \frac{36.111\,[\frac{m}{s}]}{30\,[\frac{frames}{s}]} = 1.204\,\frac{m}{frame}. \tag{1}$$

So at a frame rate of 60 fps at the same speed, a distance of

$$d = \frac{36.111\,[\frac{m}{s}]}{60\,[\frac{frames}{s}]} = 0.602\,\frac{m}{frame} \tag{2}$$

is covered. A slowdown of one frame means that the test results deviate from 0.602 to 1,204 meters. Due to the high speed of the car and camera, as well as the need for high precision in object placement, it is clear that the requirements for this AR application are much stricter than the usual human user application.

F. Visualisation for the Testdriver

The main task of the Human-Machine-Interface (HMI) is to make the AR perceptible to the test driver in real time that the ADAS functions of the test vehicle, as well as the human interaction, can be evaluated. The acceptance of the HMI as an interface for the experience plays an important role. This depends for the most part on the quality of the display, interaction and haptics [18]. For our approach, the selection of a suitable HMI concept focuses on visualization and interaction. To display AR visibly, the use of a suitable HMI or a corresponding display is necessary. Possible screen approaches are classified into feature classes based on their properties. Displays that use a medium-direct view through to the real environment in 3D belong to the class of see-through (ST) displays. Monitor-based (MB) displays only allow an indirect view of the real environment. Live or stored videos (2D) are used for this technology. Indirect displays (3D objects: video ST), which visualise AR in 3D using video, also belong to the group of ST displays. The 3D concept is crucial here. The processing of the 2D camera data of the real environment used, through 3D scene modelling, makes it possible in the first place to integrate the virtual objects in the correct perspective (2D). Video-based ST displays (video ST) are used if the recording and playback of this same AR on an indirect display take place almost simultaneously. Optical ST displays (3D-Objects:optical ST) are used when the reproduction of the virtual objects in combination with the direct view of the real environment is correctly integrated. The visualisation of AR according to Azuma limits the AR-capable displays to those that can display virtual 3-dimensional objects correctly oriented in perspective [13]. For the identification of suitable HMI approaches for testing camera-based ADAS, only these ST displays fulfil the necessary criteria.

HMI approaches in which stationary displays are mechanically fixed to the vehicle for the duration of the test belong to the Head-Up-Display (HUD) group. Head-Up-Displays used in automotive vehicles to show the driver the actual speed or using the display of a smartphone or tablet belongs to this category. Those in which the display is attached to the head like when using Virtual Reality (VR)-glasses or AR-glasses belong to the Head-Mounted-Display (HMD) group [19]. In both HMD and HUD, HMI approaches of optical and video-based ST displays are identified. In the further progress of the approach to use AR as a visualization for the driver, different evaluations must be carried out.

G. Further Thoughts about Using Augmented Reality Simulation for Testing Advanced Driver Assistance Systems in Future Automotive Vehicles

In the first step, the focus of our approach will shift to camera-based sensors. Only a few ADAS functions, such as traffic sign recognition or Lane Departure Warning (LDW), access the camera's sensors. To evaluate further tests and to achieve the identical behavior of the ADAS-ECU (see Figure 3) in reality as when using AR, the integration of more sensors, such as radar or lidar, is required. It should also be mentioned that the Euro NCAP test scenarios are only carried out under ideal conditions according to the current status of the position of the sun at midday with little or no shadows and reflections, no other road users, no rain, etc. [16]. Our approach aims to further increase the complexity and realism of Euro NCAP test scenarios.

V. CONCLUSION

In this article, we proposed an approach to using AR in automobiles. Using AR in ADAS aims to combine the advantages of simulated test procedures, such as reproducibility and cost savings, with the benefits of real test procedures (complexity of the entire vehicle and the environment). We model the problem of creating an urban environment to use AR for testing in high-speed ADAS. Our approach is based on a combination of vSLAM algorithms with AI and IS for object detection. That should help get better overall performance in terms of computational speed and accuracy. The creation of a virtual 3D environment with a better understanding of individual objects should make it possible in a later step to enrich other sensors, such as car radar and lidar, with objects in addition to camera data. That should further increase the overall performance of the entire system. The lessons learned so far are mainly regarding the SLAM-Algorithms. In automotive test fields, the current state-of-the-art SLAM algorithms are not well suited for environmental conditions such as low textured environment and high camera velocity. Further problems are the software runtime since the test system must work in real-time and the reproducibility. We hope to overcome at least some of these challenges, as mentioned beforehand, by combining neural networks with modern SLAM algorithms. This approach is intended not only to create a link between real and virtual test procedures but also to increase the complexity of potential test procedures, accelerate the development speed of ADAS functions and improve safety for future mobility solutions.

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