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The Role of AR/VR in the development of Autonomous Vehicles a subset of software defined vehicles – A survey

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Abstract

The integration of Augmented Reality (AR) and Virtual Reality (VR) technologies in the development of autonomous vehicles (AVs) addresses critical challenges such as safety, cost, and the "reality gap." This survey explores three key methodologies: sim2real, which transfers knowledge from simulations to real-world applications; VR simulation, which utilizes digital twins for immersive testing environments; and Parallel Intelligence Technologies, which enhance system control through real-time data integration. By improving training scenarios and user trust through effective communication interfaces, AR/VR can significantly advance the capabilities of autonomous driving systems. The findings highlight the importance of further research to optimize these technologies for safer and more efficient AV deployment.

Keywords:

Autonomous Vehicles, Augmented Reality, Virtual Reality, Reality Gap, Parallel Intelligence Technologies

1. Introduction

The rise in demand for autonomous vehicles (with autonomous driving technologies) which is a subset of software defined vehicles necessitates addressing safety and cost concerns. There is a need for extensive simulation and real-world testing. Testing the algorithms separately in the lab environment and deploying directly in a vehicle can be disastrous sometimes. It also involves huge cost considering the sensors of high precision, cameras and radars as well as damage to a real vehicle caused by a collision if any. The simulated environment and real environment can be completely different and there lies a gap between the simulated and real worlds such as lighting, textures, vehicles dynamics and behaviors of agents. This gap is called “reality gap” [2]. To eliminate this reality gap and to connect the simulation and reality many methods have been proposed [1]. These methods are categorized and are specified in [1]. The categories are of three types. 1) sim2real: which transfers knowledge from simulation to reality. 2)Virtual Reality

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simulation: that involves a combination of Digital twins and Virtual reality and study various scenarios involving all sensor data in a virtual simulation world (CARLA is one example of Autonomous Vehicle VR simulation). This method is also used for various experiments like pedestrian and AV interaction, passenger safety and trust etc.; 3) Parallel Intelligence Technologies: which is advanced technology and combines the advantages of both sim2real and digital twinning methods.

2. Brief introduction to all the three methods:

2.1. Sim2real:

In this approach the knowledge and strategies learned from the simulation or simulated world is transferred to the real world to eliminate the "reality gap". The core idea behind the Sim2real in the field of autonomous driving is to train the autonomous driving system in simulated environments and apply them to the real world vehicles. According to [1] there are some factors which are causing the "reality gap". These factors include uneven sampling in the real world, many physical parameters, insufficient expert experience and imperfect dynamics models.

2.1.1. Uneven Sampling in the Real World:

This factor points to the fact that not all the nuances of the real world are captured due to either limited data collection or biased data collection. For suppose if the model is trained and tested for only a few certain scenarios, it might not perform well for other conditions which are unrepresented.

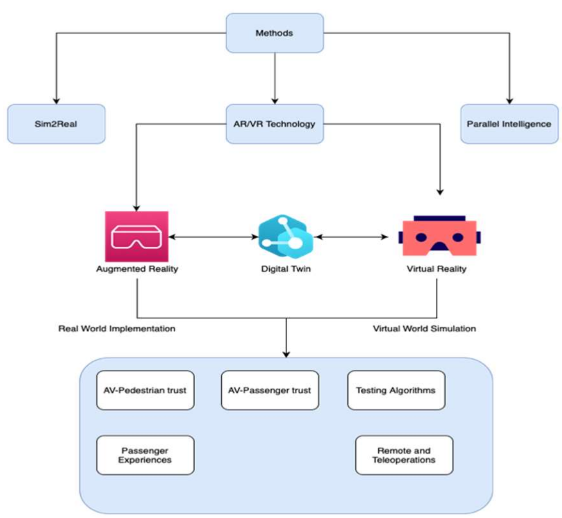

Figure 1: Various Methods for filling the "reality gap" RG

2.1.2. Many Physical Parameters:

Real world systems are influenced by many physical parameters such as friction, air resistance and road conditions and if these are omitted in the process of simulation the results might not be accurate.

2.1.3. Insufficient Expert Experience:

Deep domain knowledge and expertise is must for developing accurate models. The expert involved in the creation of these models lack understanding of complex dynamics of the real system the resultant models might not capture all relevant factors.

2.1.4 Imperfect Dynamics Models:

It refers to the fact that if the interactions between various components of a system are not accurately simulated by a model, then it might produce results that differ from those observed in practice. In order to eliminate “reality gap” caused by the above mentioned factors sim2real has been gradually developed using various methods that includes curriculum learning, meta-learning, knowledge distillation, robust reinforcement learning, transfer learning (which are not of course the topic of interest). Each method uses unique ways to solve the “reality gap” but as mentioned by [1] the computational cost of sim2real is still a challenge when dealing with complex and dynamic environments which is a cause for limiting the scalability of sime2real.

2.2. Virtual Reality Simulation:

Though Sim2real methods for autonomous driving have made good progress, the transfer of driving strategies from virtual simulation to real world is still a challenge [1]. Fine tuning of related algorithms for validating the design requirements in a real physical environment with different scenarios can be time consuming and expensive which paved the way for virtual reality simulation.

2.2.1. Digital Twins in combination with AR/VR:

“The main idea of DTs, as an important embodied part of VR is a virtual copy or model of any physical entity (physical twin) and both of them are interconnected by real time data exchange.” [1]. The digital twin technology is said to be an extension of augmented reality and mixed reality. VR/AR/MR technologies mentioned above have significant influence on the simulation works and lead to the possibilities for the applications of DTs in the autonomous driving field.

2.2.1.1. Emphasizing more on VR, AR and MR

Coming to Virtual Reality, it is a technology that creates a simulated environment and immerses users in a fully interactive 3D world that can be completely different from the real world that we are in (but it looks similar). The immersive experience that we get while using VR is achieved through specialized hardware like VR headsets, which mainly provide a stereoscopic view and input devices like controllers and hand movement recognition sensors, that allow users to interact with the virtual environment as if they are physically present within it. Simply speaking about Augmented Reality, it is a technology that enhances the real world with virtual content. In other words it enhances the perception of the physical world by the integration of virtual objects into image sequences that are obtained from various cameras, allowing users to interact with the virtual objects in real time [3]. Augmented Reality (AR) and Mixed Reality (MR) sometimes look alike and are closely related technologies. This is the reason why it can sometimes lead to confusion due to their overlapping characteristics. These two technologies involve enhancing the real world by integrating the virtual content with the real world. But MR extends this by allowing virtual and real objects to interact with each other in real time. MR includes both augmented reality and augmented virtuality. In the autonomous vehicle system an MR can help both in overlaying the interactive virtual content onto the real world to help the passenger understand the next move of the autonomous vehicle and also integrating the real objects into the virtual world environment so that the simulation ability in the framework is more crucial compared with AR. A space is created in such a way that it accommodates both virtual and real elements coexistence and allow an interaction between them. A gap between the simulation and reality can be bridged with the help of MR by enabling a seamless interaction between real (physical) and created (virtual) objects that exists in real or virtual world environments.

2.2.1.2. Trusting the Autonomous Vehicle (Both in and out)

Trust in most literature surveys is discussed in two ways: the first one is the trust of pedestrians in autonomous vehicles [4, 5, 6] and the second one is the trust of passengers of autonomous vehicles. Mostly VR is used to test the communication between pedestrians and autonomous vehicles in a simulated environment and correct the algorithms. But the trust of passengers of autonomous vehicles is experimented using AR windshields to highlight the next moves, detected objects etc. to communicate with the passenger. Let us talk about few research done. In [4] the author has done a review of all the works done on VR simulation to study AV-Pedestrian interaction. Mainly these studies are done for observing the behavior of the pedestrians in various challenging conditions and the response from the AV algorithms or AV itself. A windshield is designed by [7] for an AR effect display which shows the perception and decision making of the autonomous driving system (Vehicle navigation and routing).They can also be used to highlight the Pedestrians and animals detected to increase the trust on the autonomous vehicle [8]. AR also can be used in combinations with IOT where in the cars communicate with each other (that includes the information about Pedestrians, traffic and speeding cars etc. and highlight beforehand to show the passengers to gain their trust.

2.2.1.2.1. Recommendations for filling the Research Gap

There are certain recommendations (AV - Pedestrian interaction) given by the author of [4] as he identifies the research gap. As most research focus on one pedestrian and one AV to test the communication and behavior of both the pedestrian and AV in VR environment, the author stresses to adopt scalability where more pedestrians and AVs along with some mixed traffic simulation (it is good if the simulation is done using some real data collected through sensors in traffic), it increases the scalability. This scalability is not touched much. Various environmental conditions where pedestrians cannot see the AVs clearly should also be studied in a VR environment. Most researchers like [9] used recasting to determine the vehicle behavior in VR. This must be enhanced with more simulated sensor data. According to his suggestion, something like a game theory model [10] can be used to determine the AV driving behavior. Basically, the Mathematical model which determines AV driving behavior can learn from the real-world human inputs while adding value to VR pedestrian simulators. In [5] the author has suggested a framework called "JOAN" for human-automated vehicle interaction and "JOAN" connects to open-source AV-simulation program CARLA which can be utilized by using an unreal engine. Recommendations for the second one (AV-Passenger) interaction, the author of [11] specifies that most investigations of navigational aids are done for manual driving. Only one study presented an AR interface for fully automated vehicles.

Work needs to be done with regards to higher levels of vehicle automation, and as part of this motion sickness should also be investigated. As the tools for AR are becoming more and more sophisticated, the use in the future is imminent. By now, through head-up displays AR is being used for navigation in some sense. There lies a novel future research direction for automated vehicles which includes the integration of navigation tasks with passenger experience. Preferring to navigate through scenic beauty and augmenting virtual cues to catch the passenger attention along with displaying the next steps (driving) to be taken by the AVs. Navigational studies should also need to address the spatial capabilities of the vehicle and passengers, the communication of depth cues and spatial information display modalities. Most studies are done indoors, and Augmented reality display systems are tested in Virtual reality environments and have to be tested more in outdoors in a real environment. Furthermore, there requires a study that considers the physiological data of the passenger being collected by the AVs. Using Artificial Intelligence the data should be analyzed and communicate to the passenger accordingly. If AVs start to understand the passenger then passenger starts to trust AVs.

2.2.1.3. Testing Algorithms with many challenges

A lot of literature spoke about testing autonomous vehicles in two different phases. In the first phase the algorithms or models are tested in complete Virtual environment (simulation) with various challenges (where VR involves) and the other literature spoke about second phase of testing where the algorithms that are corrected in the first phase are implemented in a real autonomous vehicle and using mixed reality (MR) are tested in a safe environment. Let us go through a little of the research done. In [12] the authors proposed a vehicle traffic simulation system which connects the SUMO simulator with real vehicles online to simulate various scenarios and provides data for vehicles in a virtual environment when testing the autonomous driving methods. [7] talks about an MR system that uses sensors for capturing vehicle state data and builds a virtual space so that it can provide many optional complex environments that can be used to test autonomous driving algorithms. For example, Imagine a company which is into the development of an autonomous can and wants to test its driving algorithm that can handle various challenging conditions like heavy rain and navigating through a busy city street with pedestrian, cyclists, animals etc.; The first thing that we do is:

Data Collection: In which the MR system uses the car's sensors to collect real-time data about its current state like speed, position surrounding objects like cars, sign boards etc.
Next, we go through the creation of **Virtual Space.** Based on the data obtained, the MR system generates a virtual environment that can include additional elements that are not present in the real world such as different weather conditions and increased traffic.
Next, we **Test with Complex Environments** in which the system simulates various complex scenarios within the virtual environment like add sudden pedestrians crossing the street or an animal suddenly coming on to the road. By testing in these diverse and challenging virtual environments the company can assess and improve the car's autonomous driving algorithms to ensure that the algorithms are robust enough to handle real-world complexities.[13] Talks about the similar type of system which is described by [7]. They have built a framework called "Sleepwalker". It is designed to verify and validate the performance of autonomous vehicles (AVs). The framework works by simulating the AV's automated driving functions at a level very close to the sensors. It introduces virtual sensor data into the system along with the real-world sensor data that AV is collecting. The Virtual data is combined with the real-world data and a MR environment is built. This environment includes both real objects and virtual objects. The experiment they did is to test the autonomous car in a spacious car testing ground with very few obstacles and using mixed reality technology they have built a virtual cellar car parking where in the autonomous car has to navigate through the pillars and park the car. Here the Car and few obstacles are real and the others are virtual and added to the sequence of data collected by the real sensors, so that the car assumes that there is an obstacle and navigates around it. In the Simulation testing part, some authors like [14] have used Generative AI - Empowered simulation for autonomous driving.

2.2.1.4. Passenger Experiences

Passenger Experience is one of the areas which is less explored and according to [11] there are a total of 12 studies on this passenger experience. Most of the studies have either used HMDs or HUDs. Only two studies along with some qualitative data have also evaluated quantitative criteria such as Physiological data, including heart rate variability and breathing rate. Passenger experience can also be part of trust. Many authors or researchers have come up with various ideas like giving entertainment to passengers with VR games or VR content. But the passengers should be cautious as they have to also observe the surroundings. Furthermore, there is a problem with current VR HMDs which can create nausea feelings for the passengers. Some authors suggested making the applications that will adjust to the speed and movement of vehicles. But further studies are required in this field of passenger experience.

2.2.1.4.1. Recommendations for filling the Research Gap

As suggested by [11] the automotive research community must start investigating comfort, anxiety, entertainment and work aspects, using virtual reality simulations for autonomous vehicles.

2.2.1.5. Remote and Teleoperation of AVs

The authors of [15] are not sure whether fully automated SAE level 5 confirmed cars will likely go for mass adoption anytime soon. So, they predicted remote monitoring and teleoperations in foreseeable future. VR can be one of the potential interfaces as predicted previously. But according to the authors perspective it has its own drawbacks which will overweight its benefits. The authors have done 3 user studies with varied number of participants. The conclusion that they came to after the 3 user studies are as follows:

- The VR interface replicating the physical interface does not outperform the physical interface.
- The perceptual issues (motion sickness, visual fatigue and depth perception) and ergonomic issues (physical discomfort, repetitive strain injuries, and limited mobility) are overweighing its benefits.
- Future VR headsets can decrease these disadvantages and lead to the increase in usage of VR for remote monitoring and teleoperations.

2.2.1.6. Conclusion and my final recommendations:

There is a lot of buzz going around trust on autonomous vehicles and more focus can be given to that. Despite technological advances trust remains as a major issue that is faced by autonomous vehicles. Most studies report that explanations of the status of automation systems plays a major role in trust of autonomous vehicles. From the above discussion on trust, we know that AVs can communicate with passengers through windshields or Head-up Displays or even Head mounted displays. There can be many creative ways to explain the status through AR. But the question here is how much explanation of status is needed. The forms of communication can be the way the information is communicated. It can be in detail like the detailed technical information or a simple and clear explanation through a visual feedback system. These factors can influence on how much trust users place in the system. These various forms can resonate differently with different users. For example, some people are comfortable with clear explanations and some people are comfortable with detailed technical explanations. These communications should be different for various driving scenarios, for instance in a complex urban environment with lots of traffic a detailed explanation of how the car might navigate should be more assuring than in a simpler and less stressful driving situation. The authors of [16] have come up with various recommendations for explanation of status by user experiments. These experiments are conducted in a VR environment and the data is obtained. They also have suggested that along with trust factors, other factors such as emotion and satisfaction should be considered. Based on collating many suggestions from various studies I concluded that, using Artificial intelligence along with various physiology and psychology data, if AVs can take decisions and communicate or explain the status to the passengers by knowing their emotion can increase

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more trust. AR can be used for real world testing and VR can be used for indoor experiments by using a simulated world for most of the scenarios.

2.3. Parallel Intelligence

Parallel intelligence is not much of my focus, but as an advanced technology parallel intelligence (PI) can reduce the "reality gap" [1]. The advantages of both sim2real and digital twin methods are combined to achieve better management and control for complex systems. PI has three functions including description intelligence, prediction intelligence and prescriptive intelligence [1]. In parallel intelligence techniques the researchers typically construct an artificial system which is mapped to a physical system to learn knowledge and give feedback to the physical system. The data that is collected can be used to make the artificial intelligence system learn knowledge and then applied to the real time system in parallel. Fusing DTs and PIs can be a greater benefit to the AV community. All these three methods require developing virtual worlds. And there are some simulators like AirSim and CARLA that we can use for further studies.

Conclusion

The integration of Augmented Reality (AR) and Virtual Reality (VR) technologies into the development of autonomous vehicles (AVs) holds significant promise for addressing the inherent challenges of safety, cost, and the reality gap. By leveraging these immersive technologies, researchers and developers can create more effective training environments that simulate complex real-world scenarios, thereby enhancing the reliability and performance of AV systems. The methodologies discussed—sim2real, VR simulation, and Parallel Intelligence Technologies offer complementary approaches that can be utilized to refine algorithms, improve user trust, and facilitate better communication between AVs and their passengers or pedestrians. As the industry continues to evolve, it is crucial to prioritize research that explores scalable simulations, user experience enhancements, and the integration of physiological data to foster greater trust in autonomous systems. Ultimately, the successful application of AR and VR in autonomous vehicle development not only promises to bridge the gap between simulation and reality but also paves the way for safer, more efficient transportation solutions in the future. Continued innovation in this field will be essential as we strive toward fully realizing the potential of autonomous driving technologies.

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