# Literature Review for Mixed Reality Simulation

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## ABSTRACT

Mixed reality is becoming more and more popular with the fast developing trend of Metaverse related concepts in recent years, the technics that mixed reality uses to present the scenarios which are inconvenient or even unable to be tested or presented in real life is useful for the corner-case simulations in autonomous driving to test the feasibility and robustness of self-driving algorithms. This paper makes a tiny literature review to show the current developing trend and modern technics in mixed reality and seeks possibilities for mixed reality simulations in autonomous driving to pave the way for high-quality simulation of conner cases in autonomous vehicles.

## INDEX TERMS

mixed reality, simulation, autonomous driving

In autonomous driving, challenging tasks always occur in some corner cases, making the corner cases one of the main research areas to be studied with. To provide better results in safety-critical systems, researchers have come up with various approaches. Contemporary methods for the simulation of autonomous vehicles usually uses the digital graphics on 2D screen to present the whole self-driving environment. Like CARLA, Airsim, Udacity, Apollo, Autoware are the most commonly used simulators for self-driving tests. They all targets computer-based devices with large screens and ignores abundant interactions that should have exist between reality and virtuality. As human-computer interaction can be integrated into mixed-reality-based simulators to enhance the entertaining aspect of the application and make the testing process more relaxing for the researchers, mixed reality simulation should not be neglected in autonomous driving.

While mixed reality systems seek to smoothly link the physical and data processing environments, mixed reality systems are becoming more prevalent, we still do not have a clear understanding of this interaction paradigm. Addressing this problem, a paper titled *Mixed Reality: A model of Mixed Interaction*[1] introduces a new interaction model called Mixed Interaction model. It adopts a unified point of view on mixed reality systems by considering the interaction modalities and forms of multimodality that are involved for defining mixed environments. The main contributions of the Mixed Interaction model is：

(1) To unify several existing approaches on mixed reality systems such as Tangible User Interfaces, Augmented Virtuality

[1] Coutrix, Céline, and Laurence Nigay. "Mixed reality: a model of mixed interaction." Proceedings of the working conference on Advanced visual interfaces. 2006.

and Augmented Reality as well as approaches dedicated to more classical GUI and in particular the model of Instrumental Interaction.

(2) To study mixed reality systems in the light of modality and multimodality.

Mixed reality also has great potentials on some of the safety-critical systems and applications for its maximum visual presentability in some real-life scenarios. A paper titled *Real-time mixed reality-based visual warning for construction workforce safety* [2] integrates Digital Twin, Deep Learning, and Mixed Reality technologies into a newly developed real-time visual warning system, which enables construction workers to proactively determine their safety status and avoid accidents. In the paper, system tests were conducted under three quasi-on-site scenarios, and the feasibility was proven in terms of synchronizing construction activities over a large area and visually representing hazard information to its users. These evidenced merits of the development testing scenarios is said to be able to improve workers' risk assessment accuracy, reinforce workers' safety behavior, and provide a new perspective for construction safety managers to analyze construction safety status.

As is known that complex simulation models, expensive hardware setup, and a highly controlled environment are often required during various stages of simulation for autonomous driving. There is a need for autonomous vehicle developers to have a more flexible approach for conducting experiments and to obtain a better understanding of how autonomous vehicles perceive the world. Mixed Reality presents a world where real and virtual elements co-exist. By merging the real and the virtual in the creation of an MR simulation environment, more insight into the robot behavior can be gained, e.g. internal vehicle information can be visualized, and cheaper and safer testing scenarios can be created by making interactions between physical and virtual objects possible. Autonomous vehicle developers should be free to introduce virtual objects in an MR simulation environment for evaluating their systems and obtain a coherent display of visual feedback and realistic simulation results. In a paper titled *Mixed Reality Simulation for Mobile Robots*[3], the researchers illustrated the significance of using mixed reality technics in robots using a mixed reality simulation tool constructed based on the 3D robot simulator Gazebo. As is pointed in the paper that though mixed reality simulation relieves offline robot simulators from recreating a complete replica of the real environment, since simulation occurs in a partially real world where certain properties, such as noise and complex physics, do not have to be modeled, mixed reality simulation is not intended to replace existing simulation methods. It is a complementary, additional step for validating the robotic software's robustness before it is deployed. As robotic software is tested using simulation methods closer to the actual real world operation, the risk and cost normally grow

[2] Wu, Shaoze, et al. "Real-time mixed reality-based visual warning for construction workforce safety." Automation in Construction 139 (2022): 104252.

[3] Chen, Ian Yen-Hung, Bruce MacDonald, and Burkhard Wunsche. "Mixed reality simulation for mobile robots." 2009 IEEE International Conference on Robotics and Automation. IEEE, 2009.

larger. However, in a mixed reality simulation, physical robots or tiny autonomous vehicles in sandbox are exposed to a real world environment, nevertheless, certain interactions can be limited to virtual objects. Their result showed that the combination of augmented reality and autonomous vehicle's views provided effective visualization of robot information and simulated objects. However, without an external view of the real physical environment for augmented reality visualization, it is still difficult to relate virtual and real information.

When robots or autonomous vehicles operate in shared environments with humans, they are expected to behave predictably, operate safely, and complete the task even with the uncertainty inherent with human interaction. Preparing such a system for deployment often requires testing the robots in an environment shared with humans in order to resolve any unanticipated autonomous vehicle's behaviors or reactions, which could be potentially dangerous to the human. In the case of a multi-robot system, uncertainty compounds and opportunities for error multiply, increasing the need for exhaustive testing in the shared environment but at the same time increasing the possibility of harm to both the vehicles and the human. Finally, as the number of components of the system (humans, autonomous vehicles, other robots, etc.) increases, controlling and debugging the system becomes more difficult. Allowing system components to operate in a combination of physical and virtual environments can provide a safer and simpler way to test these interactions, not only by separating the system components, but also by allowing a gradual transition of the system components into shared physical environments. Such a mixed reality platform is a powerful testing tool that can address these issues and has been used to varying degrees in robotics and other fields. In another paper titled *Mixed Reality for Robotics* [4], the researchers introduced mixed reality as a tool for multi-robot research and discussed the necessary components for effective use. They demonstrated three practical applications using different simulators to showcase the benefits of the mixed reality approach to simulation and development and also provided a testbed for Mixed Reality with three different virtual robotics environments in combination with the Crazyflie 2.0 quadcopter. It is highlighted that the spatial flexibility, elimination of safety risks, simplification of debugging, unconstrained additions to robots and scaling up swarms are 5 obvious benefits of mixed reality for robotics.

In another literature review titled *A Review on Mixed Reality: Current Trends, Challenges and Prospects*[5], the researchers studied intensive research to obtain a comprehensive framework for mixed reality applications. The suggested framework comprises five layers: the first layer considers system components; the second and third layers focus on architectural issues for component integration; the fourth layer is the application layer that executes the

[4] Hoenig, Wolfgang, et al. "Mixed reality for robotics." 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2015.

[5] Rokhsaritalemi, Somaiieh, Abolghasem Sadeghi-Niaraki, and Soo-Mi Choi. "A review on mixed reality: Current trends, challenges and prospects." Applied Sciences 10.2 (2020): 636.

architecture; and the fifth layer is the user interface layer that enables user interaction. The merits of the study are to act as a proper resource for mixed reality basic concepts, introduce mixed reality development steps and analytical models, a simulation toolkit, system types, and architecture types, in addition to practical issues for stakeholders such as considering mixed reality on different domains.

Along with the prevalence of Metaverse, more and more researchers are seeking approaches to come up with something new relevant to their own research area. When it comes to the utility of mixed reality technologies in autonomous driving, a paper titled *Study of Social Presence While Interacting in Metaverse with an Augmented Avatar during Autonomous Driving*[6] presented the effects of using Microsoft HoloLens 2 in a Metaverse-based collaborative mixed reality environment on the driver's social presence while using an autonomous driving system. In the paper, it is described that in (semi-)autonomous vehicles the driver is the system's monitor, and the driving process becomes a secondary task. Their approach is said to be motivated by the advent of Microsoft Mesh XR technology that enables immersion in multi-person, shared mixed reality environments. They conducted a user study comparing the effects on social presence in two scenarios: baseline and mixed reality collaboration. During the baseline condition, participants communicated and interacted with another person using Skype/Meet which was installed on a mobile tablet. In the second scenario the participants used the Microsoft Mesh application installed on HoloLens 2 to collaborate in a mixed reality environment where each user is represented by an augmented 3D avatar. During the experiment, the participant had to perform a social interaction tell-a-lie task and a remote collaborative tic-tac-toe game, while also monitoring the vehicle's behavior. The social presence was measured using the Harms and Biocca questionnaire, one of the most widely used tools for evaluating the user's experience. The result comes that there are significant statistical differences for Co-presence, Perceived Emotional Interdependence, and Perceived Behavioral Interdependence, and participants were able to easily interact with the avatar in the mixed reality scenario. The proposed study procedure could be taken further to assess the driver's performance during handover procedures, especially when the autonomous driving system encounters a critical situation.

To sum up, due to the fast developing trend of Metaverse, mixed reality is playing more roles in more areas. As it is a technology that mainly holds user interaction and presents virtual objects mixed with real objects, its potential for the presenting of multiple scenarios in autonomous driving, in testing of the algorithms for corner cases in autonomous vehicles and for some other purposes is quite obvious. But in order to make the mixed reality closer to common people's life, its basic modules or functions such as interaction module, network module, object/environment detection function, etc. are yet to be optimized.

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[6] Voinea, Gheorghe Daniel, et al. "Study of Social Presence While Interacting in Metaverse with an Augmented Avatar during Autonomous Driving." Applied Sciences 12.22 (2022): 11804.

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