Chapter 8

Enhancing Human–Automated Vehicle Interaction in Complex Environments Using Virtual and Extended Reality Technologies

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ABSTRACT

The integration of autonomous vehicles (AVs) into urban ecosystems demands a comprehensive understanding of pedestrian-AV interactions, particularly at unconstrained intersections where unpredictability and communication gaps can compromise safety. This chapter explores critical challenges in AV decision-making,

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pedestrian behavior modeling, and ethical considerations in dynamic environments. We highlight the potential of Extended Reality (XR) to simulate real-world traffic scenarios, enabling cost-effective testing and behavior analysis. Through a comparative study of simulation tools like CARLA, SUMO, Unity, and Unreal Engine, we propose a virtual framework for designing and evaluating external Human-Machine Interfaces (eHMIs). Emphasizing cognitive modeling, trajectory prediction, and sensor fusion, this chapter contributes to the development of safer, more intuitive AV systems capable of navigating complex pedestrian interactions with increased reliability and public trust.

1. INTRODUCTION

Autonomous vehicles (AVs) that can drive without the supervision or intervention of a human driver, i.e., SAE levels 2 and onwards (SAE International, 2021), are becoming a reality. AVs have the potential to reduce fossil fuel consumption, improve road safety, and provide greater transportation. These potential benefits depend on public acceptance of AVs. Despite the potential benefits of AVs, public skepticism over safety is still a major barrier to AV acceptance.

Researchers studying human-AV interactions have begun to examine the topic of human trust in AVs. However, much of this research (Hoffman & Gray, 2020) has been directed at human–AV interactions within the AV itself. This existing research focuses on identifying and examining the factors promoting the trust of drivers in AVs and the implications of drivers trusting AVs. Pedestrians and other road users outside the AV have received less attention. Even so, AVs must be accepted by both riders and those outside the vehicle, including pedestrians and other road users. Pedestrian vulnerability in roadway interactions has led to increased interest in studying their trust in AVs.

The interaction of humans with human-driven vehicles (HDVs) has highlighted the importance of non-verbal communication to ensure safety (Bellan, 2024). Human drivers engage in non-verbal communication via eye contact, facial expressions, and hand gestures. This is often done to communicate the intent of drivers when negotiating the right-of-way with pedestrians. In the absence of a human driver, it is not surprising that pedestrians have expressed concerns over not knowing or understanding the intention of AVs. Understanding the intention of the vehicle is expected to foster trust in the AV and support its acceptance (Rasouli & Tsotsos, 2018).

AVs can communicate their intent through explicit or implicit means. Traditional methods of explicit communication in HDVs include indicator lamps, brake lamps, and horns. Current research on AV explicit communication focuses on the use of

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