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ABSTRACT

Self-driving cars raise safety concerns, particularly regarding pedestrian interactions. Current research lacks a systematic understanding of these interactions in diverse scenarios. Autonomous Vehicle (AV) performance can vary due to perception accuracy, algorithm reliability, and environmental dynamics. This study examines AV-pedestrian safety issues, focusing on low visibility conditions, using a co-simulation framework combining virtual reality and an autonomous driving simulator. 40 experiments were conducted, extracting surrogate safety measures (SSMs) from AV and pedestrian trajectories. The results indicate that low visibility can impair AV performance, increasing conflict risks for pedestrians. AV algorithms may require further enhancements and validations for consistent safety performance in low visibility scenarios.

Keywords: Autonomous Vehicles; Pedestrians; Virtual Reality; CARLA Simulator; Conflict Risk; Simulation; Safety

INTRODUCTION

Walking remains a popular mode of transport, but pedestrians face higher risks of collisions and severe impacts. Pedestrian fatalities, mostly occurring at night, account for 16.78% of all traffic deaths in 2020 [1]. Reduced visibility during nighttime presents challenges to pedestrian safety, especially on poorly lit roads. Meanwhile, autonomous vehicles (AVs) have the potential to improve safety by minimizing human errors. However, their acceptance, adaptation, and impact on pedestrian safety remain unclear. AV performance relies on perception systems and artificial intelligence (AI) algorithms, which may not handle all situations accurately. This concern is magnified in low-visibility conditions when data quality may affect algorithm performance and evaluating AI in these conditions is crucial but underexplored due to limited pedestrian field tests.

This paper investigates pedestrian-AV safety risks using advanced simulation and virtual reality (VR) technologies. With human-in-the-loop (HITL) approach, our goal is to evaluate conflict risk changes between AVs and pedestrians in different environments. The primary contribution is quantifying AV safety risks to pedestrians in various contexts through simulation, addressing existing research gaps and identifying effective conflict mitigation strategies.

METHODOLOGY

A high-fidelity co-simulation framework with the integration of VR technology for immersive pedestrian-AV interaction studies in various visibility condition was developed to address the limitations of real-world testing. Our framework extends the open-source CARLA autonomous driving simulator [2], offering realistic rendering, real-world physics, custom traffic scenarios, sensor options, and adjustable weather and time settings. This enables studying pedestrian-AV safety in nighttime and low-visibility conditions effectively.

In the nighttime scenario, vehicle headlamps and streetlights were on. An AV approached a pedestrian preparing to cross a straight street, maintaining a target speed of 13.12 ft/s (4 m/s). The pedestrian observed the environment through the VR headset and adjusted walking behavior accordingly. Our framework offers greater freedom and high-fidelity scenarios compared to other VR-based pedestrian-AV interaction studies, enabling more realistic data collection for AI model training and testing in AV pedestrian yielding.

RESULTS

The framework simulated 40 experiments, supporting one participant at a time. Each scenario was conducted ten times with a single VR headset-wearing user to account for walking pace variations: (i) black-clothed pedestrian in daytime; (ii) black-clothed pedestrian at nighttime; (iii) white-clothed pedestrian in daytime; and (iv) white-clothed pedestrian at nighttime.

Post encroachment times (PETs) were derived for each scenario using pedestrian avatar and AV trajectory data. AV performance could not guarantee safe stopping distances, and pedestrian walking speeds varied. Lower PETs occurred when the pedestrian crossed while the AV was far away and undetected. Pedestrians could walk faster to avoid conflicts. Slow pedestrian movement led to AVs stopping and taking time to reaccelerate, resulting in larger PETs. Pedestrian trajectories were realistic, as they did not follow straight lines at constant speeds, unlike non-HITL implementations. Nighttime scenarios had lower PETs than daytime scenarios, indicating higher risks for nighttime pedestrian crossings. Figure 1 shows PET distributions for each scenario and their relationship with pedestrian walking speeds.

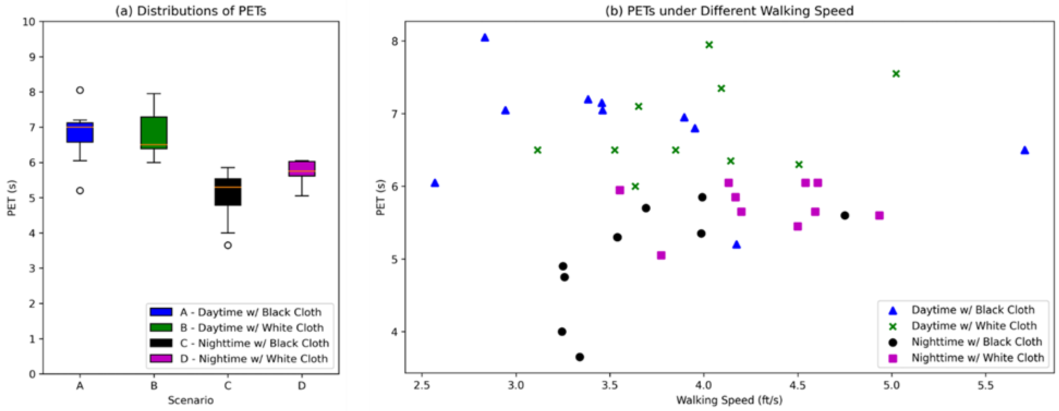

Figure 1. Distribution of PETs in Different Experiment Settings.

CONCLUSION

In this study, we used a high-fidelity, HITL co-simulation framework to analyze pedestrian-AV safety during low visibility conditions, aiming to effectively evaluate AV algorithm reliability. The framework enables interaction in a virtual environment created with advanced VR technologies and an autonomous driving simulator. Our solution offers a low-cost method for advanced AV safety research, eliminating the need for dangerous field tests. Results showed visibility as a crucial factor affecting AV algorithm performance, with nighttime posing higher risks for pedestrian-AV conflicts. Pedestrians wearing different colored attire experienced varying conflict risks at night. These findings emphasize the need to improve AV algorithms and raise pedestrian awareness regarding increased risks in low visibility conditions.

While our approach successfully assessed pedestrian-AV safety, there are areas for improvement. Including background sounds, supporting group behavior, incorporating micro-behaviors, and integrating an eye-tracking module could enhance realism, user immersion, and data collection on human factors in future studies.

REFERENCES

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