VR-PAVIB: The Virtual Reality Pedestrian-Autonomous Vehicle Interaction Benchmark

Ana Fiona Dalipi*, Purdue University, West Lafayette, IN, USA, adalipi@purdue.edu

Dongfang Liu*, Purdue University, West Lafayette, IN, USA, liu2538@purdue.edu

Xiaolei Guo, Purdue University, West Lafayette, IN, USA, guo579@purdue.edu

Yingjie Chen, Purdue University, West Lafayette, IN, USA, victorchen@purdue.edu

Christos Mousas†, Purdue University, West Lafayette, IN, USA, cmousas@purdue.edu

Figure 1: A participant experiencing a road crossing interaction scenario with an autonomous vehicle in our lab space that was designed using VR-PAVIB.

ABSTRACT

Autonomous vehicles (AVs) are an emerging theme for future transportation. However, research on pedestrian-AV interaction, which promotes pedestrian safety during autonomous driving, is not a well-explored domain. One challenge preventing the development of pedestrian-AV interaction research is that there is no publicly available and standardized benchmark to allow researchers to investigate how different interfaces could help pedestrians communicate with AVs. To resolve this challenge, we introduce the Virtual Reality Pedestrian-Autonomous Vehicle Interaction Benchmark (VR-PAVIB). VR-PAVIB is a standardized platform that can be used to reproduce interaction scenarios and compare results. Our benchmark provides state-of-the-art functionalities that can easily be implemented in any interaction scenario authored by a user. The VR-PAVIB can easily be used in a controlled lab space using low-cost virtual reality equipment. We have released our project code and include the automotive user interface community to extend VR-PAVIB.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; • **Software and its engineering** → **Development frameworks and environments**.

KEYWORDS

Pedestrian-autonomous vehicle interaction, interaction interface, virtual reality benchmark

*Both authors contributed equally to this research.
†Corresponding author.

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1 INTRODUCTION

Interaction between autonomous vehicles (AVs) and pedestrians is critical for autonomous driving [1]. Using advanced user interfaces for communication, AVs could provide safer interaction between pedestrians and AVs to improve overall system safety. However, automotive user interfaces for pedestrian-AV interaction is largely underexplored [9].

To investigate pedestrian-AV interaction, researchers need a benchmark for pedestrians' responses to different automotive user interfaces for communication. Researchers have conducted a number of studies using real-world field tests [1, 4, 8]; however, these studies have many limitations. The majority of field tests are conducted in a controlled environment that cannot reflect real traffic scenarios [3]. Thus, most of the test results cannot be reproduced and offer limited value for real practice [5]. Moreover, field tests demand high research revenue and suffer from potential risks to participants [16]. As an alternative, several attempts have been made to use virtual reality platforms to explore pedestrian-AV interaction [1, 3, 10, 11]. Nonetheless, the existing research using virtual reality platforms has had limited traffic scenarios for interaction tests. Additionally, none of the existing works have released their project platforms for other researchers to use and conduct similar research.

In this paper, we implement an open-source benchmark. Using our benchmark, research can easily investigate different user interfaces and have a fair comparison of their interface designs. Our work distills the difficulty of collecting pedestrian data in response to pedestrian-AV interaction. The major contributions of the VR-PAVIB are: (1) it simulates real interaction scenarios between pedestrians and AVs; (2) it includes a popular automotive user interface library from existing research that provides necessary elements researchers need to design and test different pedestrian-AV interaction scenarios; (3) it has no known risks for participants; and (4) it is open-source and can be easily used in a controlled lab space using low-cost virtual-reality equipment, such as Google Cardboard. Our code is available at https://github.com/anafdal/AV-Simulation.

2 RELATED WORK

A large array of research on pedestrian-AV interaction has been conducted recently using virtual reality [3, 15]. Existing automotive user interfaces for pedestrian-AV interaction can be categorized into three types: visual signs, audio messages, and haptic feedback [14, 18]. Visual signs account for the majority of pedestrian-AV interaction interfaces and have various forms. The simplest form can be found from Lagström and Lundgren [12], who use the lighting pattern of an LED array to indicate when a vehicle is in autonomous driving mode. Others show text messages or pictograms to communicate with pedestrians [1, 6]. Many studies suggest that pedestrians could easily accept messages using universal symbols or language to ensure an intuitive interaction process [1, 2, 16]. Audio messages could also facilitate this communication process with minimal explicit effort. Audio messages are particularly helpful for pedestrians with vision loss [1, 2, 16]. Pedestrians can also use wearable sensors that transmit haptic signals to pedestrians regarding the intentions of AVs [7]. Portable devices such as smart phones or fitness trackers can communicate with pedestrians via vibrations [13, 14].

Existing virtual-reality-based research generally has very simple traffic scenarios and includes limited user interfaces to be tested. None of the existing works are open-source for other researchers to use. To address these limitations, VR-PAVIB was created as an open-source benchmark that allows users to experience different human-AV communication methods. We include an interface library that includes visual signs, audio messages, and haptic feedback for users to modify and test their own ideas for pedestrian-AV interaction.

3 THE VR-PAVIB

We leveraged information that we collected from existing literature to inform the implementation of VR-PAVIB. The benchmark has been developed as a Unity3D add-on to guide vehicles in their paths and determine where they need to go next. We elaborate the functionalities and design details of VR-PAVIB in the following sections.

3.1 Interface Library

We considered all user interface designs from the related work in Section 2. We purposefully selected designs from research with many citations (≥60) into the VR-PAVIB benchmark interface library. Our interface library includes visual sign, audio message, and haptic feedback options. Based on the paradigm of pedestrian-AV interaction from Rasouli and Tsotsos [16] and Rothenbücher et al. [17], we model pedestrian-AV interaction procedures into three phases: (1) the re-starting phase, in which the AV starts to move and pedestrians cannot cross the street; (2) the stopping and yielding phase, where the AV stops and pedestrians can cross the street; and (3) the approaching phase, where the AV has detected pedestrians or slowed down to obey traffic laws (stop signs or red lights). For each phase, the associated interfaces are demonstrated. For visual signs, we sub-categorize the interfaces into pictogram signs, physical signs, projecting signs, and text signs. For audio messages, we have human-like voices, car sounds, and nonverbal sounds. For haptic feedback, we include incremental vibrations for the approaching phase, intermittent vibrations for the stopping and yielding phase, and intense vibrations for the re-starting phase. Fig. 1 shows an example of our designs for the proposed interface library during a simple road crossing interaction scenario. Our interfaces are simple, universal, and explicit, so it is easy for pedestrians to understand.

3.2 Scene Settings

VR-PAVIB has a street map that is 120×170 square meters (as shown in Fig. 2). On the street map, we endeavored to include scenes where pedestrians have to interact frequently with AVs. Thus, we implemented a mall street loop that includes crosswalks, traffic lights, stop signs, parking lots, and walking zones; these places have a high frequency of pedestrian-AV interaction [16, 17]. When

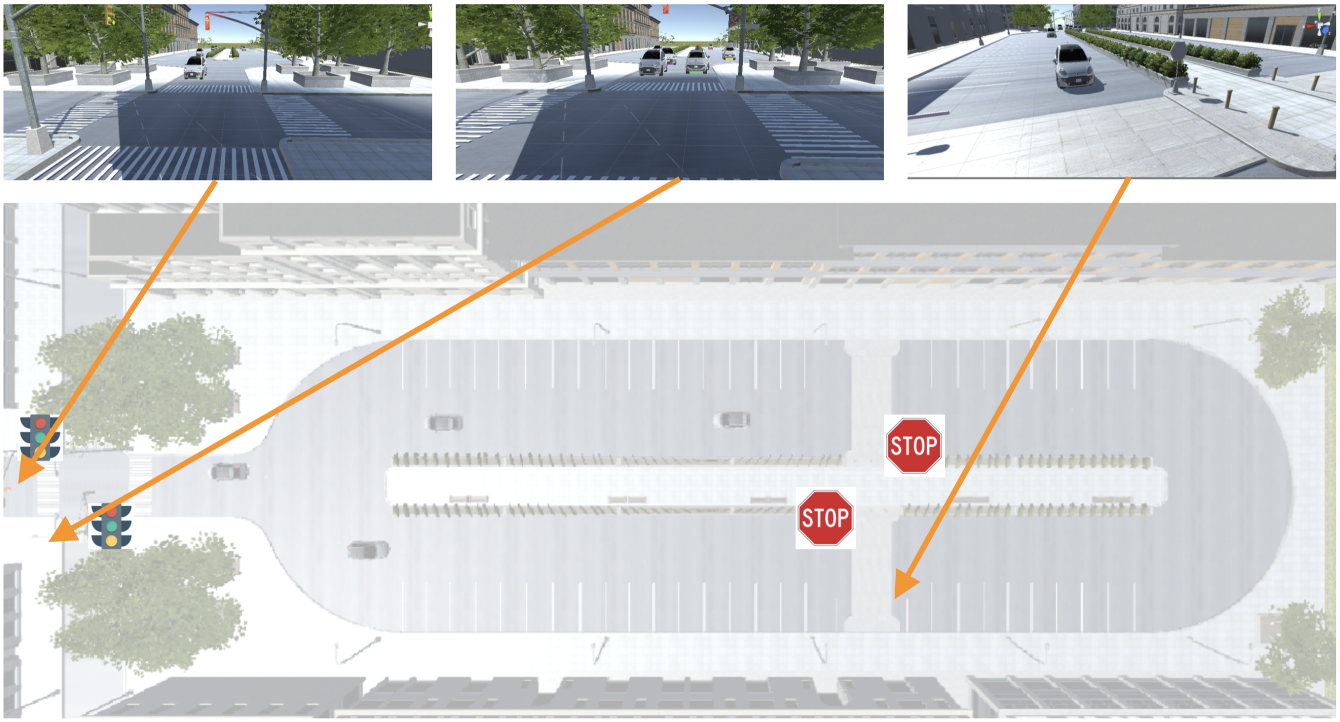

Figure 2: The aerial-view map of VR-PAVIB is shown at the bottom. The first-person views at stop signs and traffic lights are at the top.

VR-PAVIB starts, traffic enters the loop from the left following the traffic lights and travels to the opposite side from the entrance. Once an AV is running inside of the loop, it can randomly park in any open parking spot. An AV is required to fully stop at a stop sign and wait for a specified amount of seconds before it can restart. If a pedestrian appears within the safety distance of 2 meters in front of an AV, the AV is required to fully stop before the pedestrian moves away and the distance between the pedestrian and AV becomes larger than the safety distance. Using VR-PAVIB, users can arbitrarily walk inside the map and interact with different AVs.

3.3 Traffic and Interaction Logic

The traffic logic depends upon what scenarios the vehicle is in. There will be different behaviors for different situations. For example, when the vehicle stops before a stop sign, it will stop for a period of time specified by the user, unless there is a pedestrian crossing the street. If a pedestrian is present, the vehicle will wait until the road is empty again. Stopping in front of a stoplight will cause the vehicle to behave in different ways, depending on factors such as which light is activated and whether someone is crossing the road. The vehicle can differentiate between these scenarios by using ray casting. Through ray casting, the vehicle is informed of what object is ahead of it and what behavior it should perform.

3.4 Interaction Data Collection

In order to examine different solutions for the automotive user interfaces, we developed embedded tools for data capture and evaluation of human-AV interaction. These include the following components:

- **Motion Capture:** A motion capture system can be used that can be easily attached to the human body and calibrated. The full-body motion of the participant can be captured for analyzing the ways that participants move when instructed to cross roads in which AVs are present, based on kinematic features of motion such as speed, curvature, and length of trajectory.
- **Eye Tracking.** Our platform also supports eye tracking functionalities through the use of an HTC Vive Eye Pro head-mounted display, which has embedded eye-tracking capabilities. Using this device, we are able to capture eye gaze data (e.g., fixation, gaze points, heat maps, areas of interest) that can later be used to understand where and how people focus during interaction with AVs.
- **Physiological Signal Capture.** Our platform supports physiological data capture (electrodermal activity) in order to investigate people's emotional reactions when interacting with AVs.
- **Questionnaire Data Collection.** A several standardized questionnaire such as the System Usability Scale (SUS) questionnaire, the Simulation Sickness Questionnaire (SSQ), the NASA Task Load Index (NASA-TLX) questionnaire, and more

could be used to understand human-AV interaction using VR-PAVIB.

Using VR-PAVIB, participants' movements, eye tracking, and electrodermal activity can be collected during experiments. All data is captured at the same frame rate to ensure frame-by-frame correspondence between the datasets. As for the questionnaire data collection, the choice of the related questionnaires is based on the nature of research questions and research types.

4 CONCLUSIONS AND FUTURE DIRECTIONS

In this paper, we introduce the VR-PAVIB to investigate different automotive user interfaces used to communicate AVs' awareness and intent to pedestrians. VR-PAVIB can simulate various pedestrian-AV interaction scenarios and can be easily modified and implemented for user studies. It can be easily used in a controlled lab space using low-cost virtual reality equipment. The current version of VR-PAVIB embraces imperative basic functionalities for a standardized benchmark platform which can also be used by the vehicle industry to test and explore different pedestrian-AV interaction concepts. Currently, VR-PAVIB includes one scene with one weather condition (daytime). For future research, we endeavor to extend VR-PAVIB and develop more traffic scenarios, weather conditions, pedestrian-AV interaction scenarios, and so forth that would make pedestrian-AV interaction more realistic.

REFERENCES

[1] Claudia Ackermann, Matthias Beggiato, Sarah Schubert, and Josef F Krems. 2019. An experimental study to investigate design and assessment criteria: What is important for communication between pedestrians and automated vehicles? *Applied ergonomics* 75 (2019), 272–282.

[2] Michael Blau, Gulsah Akar, and Jack Nasar. 2018. Driverless vehicles' potential influence on bicyclist facility preferences. *International journal of sustainable transportation* 12, 9 (2018), 665–674.

[3] Shuchisnigdha Deb, Lesley J Strawderman, and Daniel W Carruth. 2018. Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation research part F: traffic psychology and behaviour* 59 (2018), 135–149.

[4] Debargha Dey, Marieke Martens, Berry Eggen, and Jacques Terken. 2017. The impact of vehicle appearance and vehicle behavior on pedestrian interaction with autonomous vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. 158–162.

[5] Debargha Dey and Jacques Terken. 2017. Pedestrian interaction with vehicles: roles of explicit and implicit communication. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 109–113.

[6] Evelyn Florentine, Mark Adam Ang, Scott Drew Pendleton, Hans Andersen, and Marcelo H Ang Jr. 2016. Pedestrian notification methods in autonomous vehicles for multi-class mobility-on-demand service. In *Proceedings of the Fourth International Conference on Human Agent Interaction*. 387–392.

[7] Michael S Gordon, James R Kozloski, Ashish Kundu, Peter K Malkin, and Clifford A Pickover. 2016. Automated control of interactions between self-driving vehicles and pedestrians. US Patent 9,483,948.

[8] Azra Habibovic, Victor Malmsten Lundgren, Jonas Andersson, Maria Klingegård, Tobias Lagström, Anna Sirkka, Johan Fagerlönn, Claes Edgren, Rikard Fredriksson, Stas Krupenia, et al. 2018. Communicating intent of automated vehicles to pedestrians. *Frontiers in psychology* 9 (2018), 1336.

[9] Lynn M Hulse, Hui Xie, and Edwin R Galea. 2018. Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age. *Safety Science* 102 (2018), 1–13.

[10] Alexandros Koilias, Christos Mousas, and Banafsheh Rekabdar. 2019. The Effects of Driving Habits on Virtual Reality Car Passenger Anxiety. In *International Conference on Virtual Reality and Augmented Reality*. Springer, 263–281.

[11] Alexandros Koilias, Christos Mousas, Banafsheh Rekabdar, and Christos-Nikolaos Anaqnostopoulos. 2019. Passenger anxiety when seated in a virtual reality self-driving car. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 1024–1025.

[12] Tobias Lagström and Victor Malmsten Lundgren. 2016. *AVIP-Autonomous vehicles' interaction with pedestrians-An investigation of pedestrian-driver communication and development of a vehicle external interface*. Master's thesis.

[13] Todd Litman. 2017. *Autonomous vehicle implementation predictions*. Victoria Transport Policy Institute Victoria, Canada.

[14] Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating awareness and intent in autonomous vehicle-pedestrian interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[15] Anantha Pillai et al. 2017. Virtual reality based study to analyse pedestrian attitude towards autonomous vehicles. (2017).

[16] Amir Rasouli and John K Tsotsos. 2019. Autonomous vehicles that interact with pedestrians: A survey of theory and practice. *IEEE transactions on intelligent transportation systems* (2019).

[17] Dirk Rothenbücher, Jamy Li, David Sirkin, Brian Mok, and Wendy Ju. 2016. Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In *2016 25th IEEE international symposium on robot and human interactive communication (RO-MAN)*. IEEE, 795–802.

[18] Marcel Walch, Kristin Lange, Martin Baumann, and Michael Weber. 2015. Autonomous driving: investigating the feasibility of car-driver handover assistance. In *Proceedings of the 7th international conference on automotive user interfaces and interactive vehicular applications*. 11–18.