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by Andri Janto

Application of LargeSpace for Investigating Pedestrians' Behaviors when Interacting with Autonomous Vehicles in Shared Spaces

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Abstract

Our research focuses on the interaction between pedestrians and AVs in shared spaces. We developed an experimental virtual reality (VR) facility named "LargeSpace" to investigate pedestrian behavior when interacting with an AV in a shared space. Trajectory analysis, distance to collision point, and deflection angle have been introduced to evaluate pedestrian behavior. The results help us design future experiments and enhance the user experience provided by LargeSpace.

Keywords: Human-machine interaction, safety, shared space, pedestrian, automated vehicles, LargeSpace.

Index Terms: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 Introduction

The use of automated vehicles (AVs) in urban areas has recently become a popular topic in traffic safety, especially regarding their interactions with pedestrians. Studies on the interaction between pedestrians and AVs are expected to provide result in an AV's system design that is suitable with pedestrians' behavior. [1, 2, 3]. However, developing an experimental setup to study pedestrian behavior when interacting with AVs is challenging for researchers and designers.

Application of virtual reality (VR) technologies is a promising approach for simulating possible difficult situations that could occur in real traffic. For example, a previous study demonstrated that using VR and omnidirectional treadmill was effective in investigating the interaction between a pedestrian and an AV on urban roads [1].

From the viewpoint of pedestrian-AV interaction research, a study in the environment of shared space is challenging because the separation between pedestrians and vehicles is generally omitted; hence, the behaviors tend to be unpredictable [4]. Research on the interaction of pedestrians with AVs in urban shared spaces using VR remains scarce. Thus, we aim to develop a VR simulation environment in which a real human pedestrian can walk around and interact with virtual AVs.

This study explains the development of an experimental setup for the interaction between a pedestrian and an AV using a large virtual reality facility. We introduce an experiment using this system as well.

2 Development of the Experimental Setup

We designed the experimental setup considering the conditions of shared spaces, AV behaviors, and pedestrian walking behaviors.

2.1 Shared Space

In many cases, shared spaces have been developed in the central area of a city. According to the definition of a shared space, streets are designed to improve pedestrian movement and comfort by reducing the dominance of motor vehicles [5]. There is no curb or level difference segregating pedestrians and vehicles. All road users, namely, cars, bicycles, or pedestrians, must have equal rights. These practices are used to empower pedestrian activities in urban areas.

Speed limits vary in different cities and countries. For instance, in New South Wales the speed limit is 10 km/h [6]; in Auckland, it is 20 km/h; in the UK, it is under 32 km/h [6].

Based on the above discussion, we chose one of the main streets around the Tsukuba Center as the experimental area. Several speed limits for AVs were tested in our experiment.

2.2 Autonomous Vehicle

An autonomous vehicle or self-driving car is a driverless vehicle that can travel between destinations using sensors and artificial intelligence to analyze road and traffic conditions. According to the Society of Automotive Engineers (SAE), there are six levels of automated driving from 0 to 5: manual driving to fully automated [7].

In our system, the AV in question is an SAE level 4 vehicle with no driver. The transportation network is a low-speed commuter system. Therefore, "eye-contact" between a pedestrian and an AV is not assumed in our experiment.

2.3 Pedestrian Walking Behaviors

We characterize the walking behavior of pedestrians based on two criteria: the choice of the next step and selection of the speed [8]. The choice of the next step assumes that pedestrians are walking by following given trajectories, and they can select from many

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alternatives to reach their destination. The choice of speed can be observed in the model of pedestrian crossing, wherein the relationship between speed, flow, and density is the main element of the model.

Pedestrian behavior theory suggests that analyzing a single pedestrian at a given location and given point in time is more convenient for the observer [8]. In addition, the analysis may integrate the influence of age and gender.

Our experimental setup needs to be able to measure the behavior as described above.

Figure 1: LargeSpace.

2.4 LargeSpace

We developed an experimental setup with a facility named "LargeSpace" [9]. "LargeSpace" is the largest encapsulated space with immersive display in the world; continuously projected images on an immersive screen offer us sufficient room to simulate complex traffic situations in a shared space. It is similar with the CAVE system [10]. LargeSpace consists of 12 projectors, ten computers, and 20 motion capture cameras. The motion capture system provides not only the position but also the speed and vision angle of the participants. Furthermore, cluster computers synchronize users' perspectives in the virtual world, which allows us to monitor the motion of participants during the experiments.

The experimental environment mimics the shared space around the Tsukuba City bus station, as shown in Fig. 1.

2.5 Participants

Since sidewalks and crossings do not exist in shared spaces, therefore elderly pedestrians are a significant concern in the development of traffic safety [11]. The population of people aged 65 and over in Japan will increase to 40% by 2050, and they remain active in society [12]. Thus, we focused on the interaction of elderly pedestrians with AVs.

Consequently, we conducted a study on elderly pedestrian behavior interacting with AVs in an urban shared space using VR.

The participants in this experiment were 10 males and 9 females, with an average age of 72.1 years, SD=3.5, range 66 – 77 years.

2.6 Experimental Design

We designed the experiment using two walk-behavior approaches. The pedestrian trajectory describes the behavior on the crosswalks and when walking straight.

Three scenarios were used in this experiment. The first scenario is the pedestrian crosswalk following points A, B, C, and D with an AV approaching from behind, as shown in Fig. 2. In the second scenario, pedestrians see the AV approaching while crossing, following points D, C, B, and A. Finally, in scenario three, pedestrians walk straight from point E to point F while the AV follows from behind.

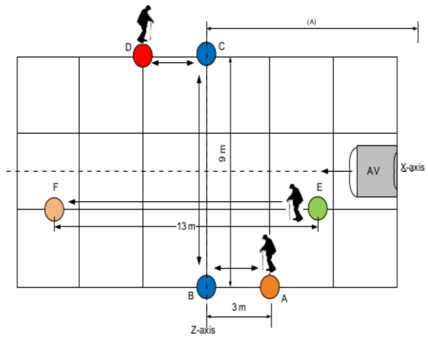

Figure 2: The three scenarios.

The AV approaches 50 m (A) from the center point and moves along the x-axis from right to left. The speed would vary between 20, 25, and 30 km/h, following the allowable speed in the shared space. The AV would not stop to let pedestrians cross because we want to investigate the acceptable speed perceived by pedestrians as safe when interacting with AVs. In addition, we will explore pedestrians' need for a human-machine interaction (HMI) interface. Therefore, the AV does not communicate its presence.

2.7 Procedure

The participants learned the procedure before the experiment. We explained how to interact with AVs in a shared space and presented the facility. Participants rehearsed each scenario. The experiment was initiated if the participant agreed.

First, we measured the normal time (Nt) using a stopwatch as the travel time for each scenario without AV intervention.

Second, participants participated in 27 sets of scenarios; each consisting of scenarios 1, 2, and 3 sequentially. The AV speeds were 20, 25, and 30 m/h randomly for each set. We calculated the number of sets by multiplying the possible speed variations of the three scenarios. The scenarios were sequential from scenario one to three; therefore, the set number would be 1*3*1*3*1*3 = 27 sets. The pair of scenario (Si) and speed (Vj) was denoted as SiVj, i=1, 2, 3 and j= 20, 25, 30. For example, the variety of sets for one participant would be set1: S1V30-S2V30-S3V30, set2: S1V25-S2V30-S3V20, ..., set27: S1V20-S2V30-S3V25. The combination sets was different for each participant. After finishing all sets, the participants were asked to fill out a questionnaire to measure their perception of safety and investigate the interface demand.

The experimental setup recorded the coordinates of the AV and participants (x, y, z-axis) and simulation time (s) for each scenario. In addition, we recorded all activities with video.

3 Data Analyses

We confirmed that all the parameters were successfully obtained and calculated from the simulator, namely, traveling time (Tt), waiting time (wt), distance to collision point (d), and deflection angle (a). We constructed the pedestrian trajectory from the measured coordinates (x,z). In addition, we counted the number of waiting instances and the number of avoidances (from collision points) during the experiment.

3.1 Traveling Time (Tt)

The traveling time is measured when pedestrians walk from the start to the finish point (s). Fig. 3 illustrates the calculation of Tt. We identified the x-coordinate at the start and finish points to determine start time (t1) and finish time (t2). For example, the beginning (-3, t1) and the finish (3, t2). Thus, Tt = t2 - t1 -wt. Tt omitted wt for comparison to Nt. We did not subtract Tt with wt for scenario three since pedestrians were not waiting for AVs to pass.

We obtained Tt as shown in Fig. 4. On average, the females walked faster than the males. Overall, Tt for males ranged between 7.8 - 25.5 s and females 2.9 - 25.4 s. Most participants claimed they did not hesitate to crosswalk in front of AV (79%) and walk side by side with AV (63%).

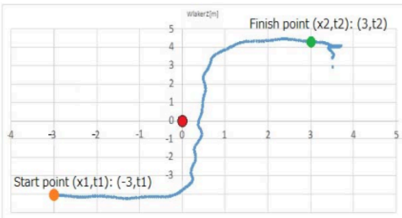

Figure 3: Traveling time trajectory.

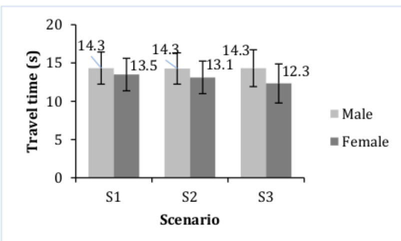

Figure 4: Average travelling time.

3.2 Waiting Time (wt)

Waiting time is measured when a pedestrian lets an AV to pass first (s). Then, we determined the pedestrian checking point to obtain the beginning time to wait (tp). Next, we chose the AV point after passing the collision point (CP) to obtain the AV passing time (tc). Thus wt = tc - tp. Fig. 5 presents the calculation steps.

The average waiting time for male and female pedestrians ranges from 0 - 10 s for scenario 1 and 0 - 7 s for scenario 2. A comparison of the average waiting numbers between scenarios 1 and 2 for each speed and gender are shown in Fig. 6 and 7. The result showed a natural waiting behavior in which the increasing speed of a vehicle would increase the number of waiting.

3.3 Distance to Collision Point (d)

The collision point distance and pedestrian path (d, meter) reflect how pedestrians avoid AVs by adopting a sloping trajectory, as depicted in Fig. 8.

The average avoidance distance for the male was 0.2 m, SD=0,07, range = 0.1 – 0.4 m. For the female, it was 0.2 m, SD=0.13. range = 0.1 – 0.7 m. However, the survey showed participants might avoid the collision point because of their behavior to crosswalk. Fifty-two percent of participants might crosswalk diagonally

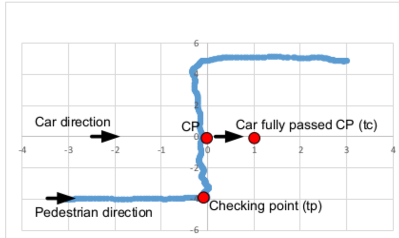

Figure 5: Waiting time.

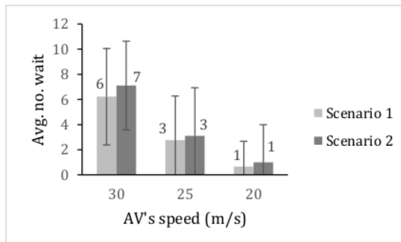

Figure 6: Male pedestrians' average number of waiting.

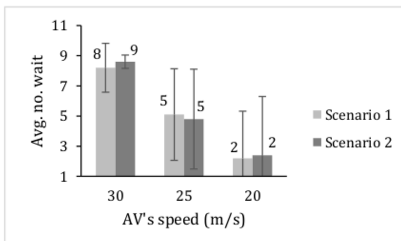

Figure 7: Female pedestrians' average number of waiting.

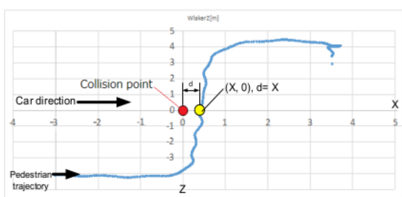

Figure 8: Distance to collision point.

3.4 Deflection Angle (a)

The angle between the straight line (start-finish in scenario 3) and pedestrian trajectory at the MP (meeting point) (degree) are shown in Fig.9. The MP is determined when the AV and pedestrian have the same position in the x-coordinate. Therefore, this angle reflects pedestrians trying to assume a greater distance from the determined path compared to the original distance because the AV passed close to them. For example, in Fig.9, a = 15.8 degrees.

After AV passed the meeting point, the male participants deviated on average 11.0 degrees, SD = 3.5, range = 6.4 - 19.0. The female participants deviated on average 11.9 degrees, SD = 4.5, range = 4.7 - 27.0. They disagreed with always behaving walking straightly. Also, most participants (79%) felt safe walking beside AV. So the deflection might not be because of interacting with AV.

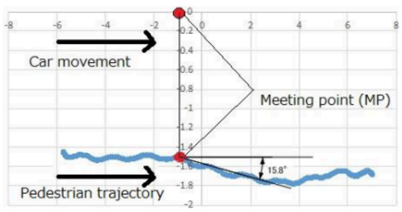

Figure 9: Deflection angle.

4 Concluding Remarks

We collected all related data experimentally. After obtaining the parameters, we used them to test the acceptance of pedestrians, especially the elderly, interacting with AVs in a shared space. However, the acceptance model has not been established yet. We are aware that there remain certain shortcomings in the experimental procedures, such as the number of participants, which was not representative of the elderly population in Japan. In addition, we were not able to further develop the behavior of the AV. for example, lane changes were not possible owing to the limitations of the simulator program used. Furthermore, the poor connectivity between the virtual glasses and simulator caused some data loss. However, we obtained valuable ideas from this experiment to develop existing facilities to support this research further.

In addition, we found that 79% of participants needed communication from AV. The interface of human-machine interactions would be a signal lamp (1), sound "beep-beep" (6), human voice (7), and music (1).

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