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Examining Pedestrian-Autonomous Vehicle Interactions in Virtual Reality

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Abstract

Autonomous vehicles now have well developed algorithms and open source software for localisation and navigation in static environments but their future interactions with other road users in mixed traffic environments, especially with pedestrians, raise some concerns. Pedestrian behaviour is complex to model and unpredictable, thus creating a big challenge for self-driving cars. This paper examines pedestrian behaviour during crossing scenarios with a game theoretic autonomous vehicle in virtual reality. In a first experiment, we recorded participants' trajectories and found that they were crossing more cautiously in VR than in previous laboratory experiments. In two other experiments, we used a gradient descent approach to investigate participants' preference for a certain AV driving style. We found that the majority of them were not expecting the car to stop in these scenarios. These results suggest that VR is an interesting tool for testing autonomous vehicle algorithms and for finding out about pedestrian preferences.

Keywords: Pedestrian crossing; Agent-Human Interactions; Autonomous Vehicles; Human Factors

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1. Introduction

The upcoming arrival of autonomous vehicles on the roads poses several concerns regarding their future interaction with other road users, in particular pedestrians and cyclists, whose behaviour is more complex and interactive. Pedestrian interaction is challenging due to multiple uncertainties in their pose estimation, gestures and intention recognition. We recently proposed a game theory model “Sequential Chicken” (Fox et al., 2018) for such interactions, where a pedestrian encounters an autonomous vehicle at an unsignalised intersection. In this model, two agents (e.g. pedestrian and/or human or autonomous driver) called *Y* and *X* are driving straight onwards each other at an unmarked intersection as in Fig. 1.

Fig. 1 Two agents negotiating for priority at an intersection

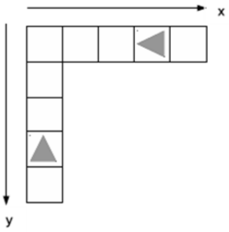


Fig. 2: Sequential Chicken Game

In the model, this process occurs over discrete space as in Fig. 2 and discrete times (‘turns’) during which the agents can adjust their discrete speeds, simultaneously selecting speeds of either 1 square per turn or 2 squares per turn, at each turn. Both agents want to pass the intersection as soon as possible to avoid travel delays, but if they collide, they are both bigger losers as they both receive a negative utility U_{crash}. Otherwise if the players pass the intersection, each receives a time delay penalty $-TU_T$, where T is the time from the start of the game and U_T represents the value of saving one turn of travel time. This model showed that their behaviour can be described by a parameter θ, which is a ratio of their utility of saving time U_T and their collision utility U_{crash}. We previously performed laboratory experiments to fit data to the game theory model. We first asked participants to play this game as a board game (Camara et al., 2018a) and secondly they were asked to play the game in person moving on squares (Camara et al., 2018b). These previous laboratory experiments have shown unrealistic results, participants preferring time saving rather than collision avoidance.

Virtual reality offers the opportunity to experiment on human behaviour in simulated real world environments that can be dangerous or difficult to study, such as pedestrian road crossing. The present study aims to extend the laboratory experiments and put participants in more realistic interaction scenarios with an autonomous vehicle in a virtual environment and learn about pedestrian behaviour preference during road-crossing scenarios.

2. Experiments

2.1 VR Setup

The study was conducted using an HTC Vice Pro head mounted display (HMD). Participants did not use the HTC Vice controllers, as no other interactions (other than walking) were required. The HMD was used with the HTC wireless adapter in order to facilitate easier movement during the simulation. We used an area of approximately 6m by 3m to conduct the simulation (as shown in Fig. 3), which was mapped using the usual HTC Vive room mapping system. The size of this area slightly exceeds that recommended by the manufacturer; however, we experienced no technical problem with tracking or system performance. The start position on the floor was marked with an ‘X’ using floor tape, so that participants knew where to stand at the start of each simulation, prior to placing the HMD on their head. The simulation was created using the Unity 3D engine, and was run under Windows 10 on a PC based on an Intel Core i7-7700K CPU, with 32GB of RAM, and an Nvidia GeForce GTX 1080 GPU.

2.2 Car behaviour model

The virtual AV, shown in Fig. 4, was designed to drive using the Sequential Chicken model described above. The car began driving 40 meters away from the intersection, its full speed was 30km/h and lowest speed was 15km/h. The vehicle moved and adapted its behaviour to participants motion. Every 0.02s, the car observed the current position of the pedestrian and made its decision based on the game theory model. The car is designed to *YIELD* sometimes by slowing down, though not stopping completely. Indeed, in the sequential chicken model, if the two players play optimally, then there must exist a non-zero probability for a collision to occur. Intuitively, if we consider an AV to be one player that always yields, it will make no progress as the other player will always take advantage over it, hence there must be some threat of collision.

Fig. 3 Participant in the experimental area

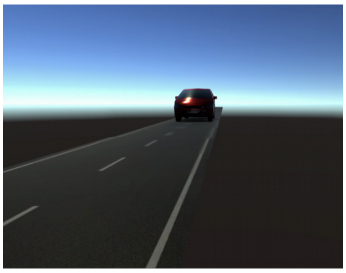


Fig. 4 Virtual autonomous vehicle

2.3 Experiment 1

We invited 11 participants, 10 males and 1 female aged between 19 and 37 years old, to take part to the study. 7 participants had previous experience with VR. Participants were asked to cross a road in front of them as they would do in everyday life. They should stop moving on their other side of the road, once they have reached a yellow cube. A vehicle was coming from their right hand side. The 3D car model was imported from Unity Asset Store. Prior to the experiment, participants were introduced to the experimental setup and trained on walking within the VR environment with VR headset. There were 6 trials per participant in the virtual environment with the first trials considered as training data.

2.4 Experiment 2

Nine participants, 7 males and 2 females, aged from 21 to 39 years old took part to this study. 7 participants had previous experience with VR. Participants were given the same instructions as in experiment 1, the environment and the vehicle were also the same. The particularity here is that participants were asked, after each interaction, whether they preferred their last interaction with the vehicle or the previous one, i.e. if they found it more “natural” or more “realistic”. At each time, the experimenter employed a gradient descent approach to discover which parameters used by the autonomous vehicle were the most appreciated by the participant. Two parameters were changed, the first one being about the spatial motion i.e the number of discrete of cells used in the Sequential Chicken model and the second parameter was about the time delay i.e the amount of time that would elapse between two decisions made by the AV. There were 8 proposed parameters in the spatial axis {3 cells, 5 cells, 10 cells, 15 cells, 20 cells, 25 cells, 30 cells, 40 cells} and 3 proposed in the temporal axis {0.02s, 0.5s, 1.0s}. The experimenter would ideally move one step along each axis per interaction.

2.5 Experiment 3

The protocol was exactly the same as in experiment 2, except that in experiment 3, the environment was designed to look more like a park or a garden, by replacing the wide tarmac road with a narrower pathway without markings as shown in Fig. 5. This was to test whether this type of environment alters pedestrian behaviour. The type of car used was also different, it was smaller, with a different colour and looked like a single person podcar as shown in Fig. 6. The 3D car model was imported from Unity Asset Store. Six participants, 5 males and 1 female, aged from 21 to 39 years old took part to the study, with 5 participants having had previous experience with VR.

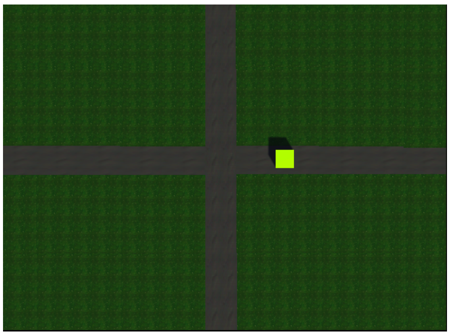


Fig. 5 Top view of experiment 3's scene

Fig. 6 Autonomous vehicle used in experiment 3

3.1 Results

3.1 Experiment 1

Among the 55 pedestrian-vehicle interactions collected, pedestrians managed to cross the road before the car arrives only 9 times. These crossings happened after the first trials, by pedestrians who felt confident after evaluating/gauging the car driving style. Most interactions looked similar to Fig. 7, which shows the interaction between one participant and the autonomous vehicle with their positions over time. This shows that pedestrians were slowing down very quickly after seeing the car, therefore they were not playing optimally the game of chicken. Following the optimal solution computation developed in Camara et al. 2018a and Camara et al. 2018b, the behavioural parameter found in this experiment is $\theta = U_{crash}/U_T = -60/8 = -7.5$, as shown in Fig. 8. This reveals that pedestrians valued 8 times a crash more than 0.02s time delay per turn, this resulting in pedestrians being less assertive in crossing the road.

3.2 Experiments 2 and 3

Using the gradient descent method, we found one most-preferred set of parameters for each participant. Examples of this method are shown in Fig. 9. As expected, it shows that different participants have different preferences for the parameters. Participants were sometimes against some parameters that gave an unexpected behaviour to the car while for some other times, they would classify two different set of parameters to result in the same driving behaviour. The results of the gradient descent method are summarized in Fig. 10 (a) for experiment 2 and in Fig. 10 (b) for experiment 3. Surprisingly, by calculating the mean value of the chosen parameters, we find similar approximate values for the two experiments, 15 cells and 0.344s in experiment 2 and 19 cells and 0.348s in experiment 3. In some cases, participants found the car behaviour as being unnatural, unrealistic, particularly in scenarios where the autonomous vehicle would slow down and then keep driving. The crossing behaviour of participants also didn't change much with a small car and a park environment in experiment 3.

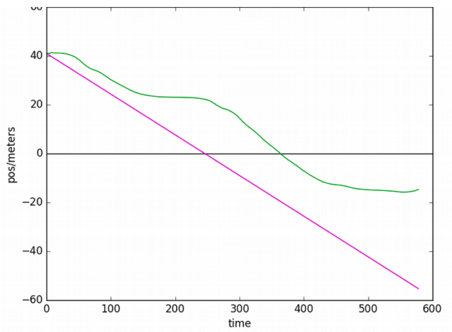


Fig. 7 Pedestrian vehicle positions over time (g: ped, m: car)

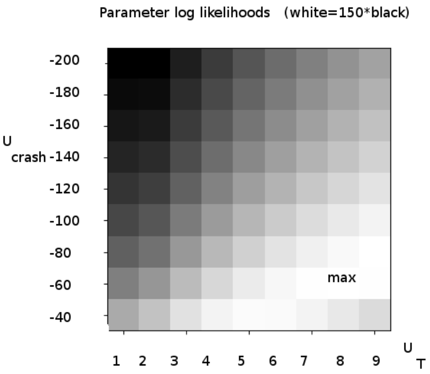
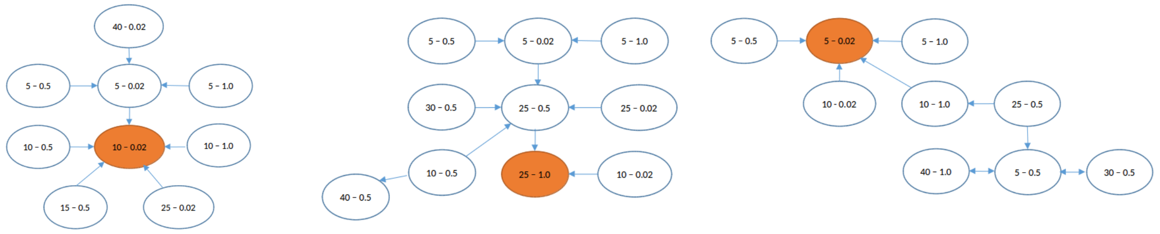
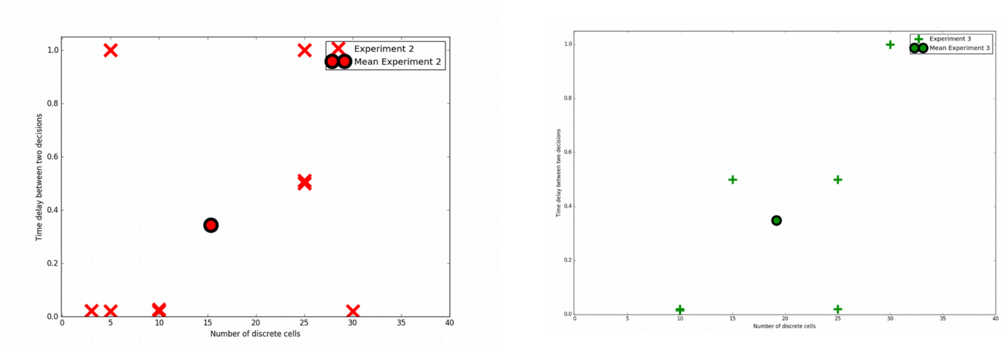


Fig. 8 Pedestrian behaviour parameter



(a) Preferred parameters: 3 cells and 0.02s (b) Preferred parameters: 25 cells and 1.0s (c) Preferred parameters: 5 cells and 0.02s

Fig. 9 Graphs showing examples of the gradient descent method for pedestrians' preferred parameter search



(a) Results for Experiment 2 (b) Results for Experiment 3

Fig. 10: Results for participants' preference for AV's driving style in experiments 2 and 3

4. Discussions and Future Work

The result in study 1 is important, as it shows that virtual reality makes pedestrian crossing behaviour more realistic than the previous laboratory experiments and therefore it can improve the development of the game theoretic model. The other two experiments showed that when interacting with an autonomous vehicle, pedestrians have some expectations towards the car behaviour, i.e whether it should slow down, keep driving or completely stop for them. In experiment 3, it appeared that the smaller car and the park environment didn't make much difference in pedestrian crossing behaviour, that is probably due to the low number of participants. There are some limitations with these experiments, in particular, the gradient descent takes a long time to run and it is hard to see what's going on, after several interactions, participants were sometimes rejecting a set of preferred parameters that they approved several times before. It is also confusing and confounding to infer parameters for both the pedestrian's own behaviour and the pedestrian's preferred behaviour of the car. Hence in future work, we next plan to put a human in a VR car to simplify the protocol. We will also evaluate pedestrian crossing behaviours with different car models and environments with a larger number of participants.

Acknowledgments

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