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Towards game theoretic AV controllers: measuring pedestrian behaviour in Virtual Reality

Fanta Camara[1,2], Patrick Dickinson[2], Natasha Merat[1] and Charles W. Fox[1,2,3]

***Abstract*— Understanding pedestrian interaction is of great importance for autonomous vehicles (AVs). The present study investigates pedestrian behaviour during crossing scenarios with an autonomous vehicle using Virtual Reality. The self-driving car is driven by a game theoretic controller which adapts its driving style to pedestrian crossing behaviour. We found that subjects value collision avoidance about 8 times more than saving 0.02 seconds. A previous lab study found time saving to be more important than collision avoidance in a highly unrealistic board game style version of the game. The present result suggests that the VR simulation reproduces real world road-crossings better than the lab study and provides a reliable test-bed for the development of game theoretic models for AVs.**

Keywords: Autonomous Vehicles; Game Theory; Cognitive architectures for action selection; Pedestrian Behaviour;

I. INTRODUCTION

The upcoming arrival of autonomous vehicles on the roads poses several concerns regarding their future interaction with other road users, in particular with pedestrians and cyclists, whose behaviour is more complex and unpredictable. Pedestrian interaction is challenging due to multiple uncertainties in their pose estimation, gestures and intention recognition. We thus recently proposed a game theory model for such interactions [3], where a pedestrian encounters an autonomous vehicle at an unsignalized intersection.

Fig. 1: Two agents negotiating for priority at an intersection

In this model, two agents (e.g. pedestrian and/or human or autonomous driver) called Y and X are driving straight towards each other at an unmarked intersection as in Fig. 1. 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.

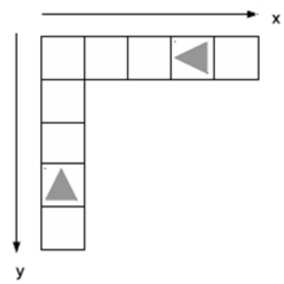

Fig. 2: Sequential Chicken Game

The model assumes that the two players choose their actions (speeds) $a_Y, a_X \in \{1,2\}$ simultaneously then implement them simultaneously, at each of several discrete-time turns. There is no lateral motion (positioning within the lanes of the roads) or communication between the agents other than via their visible positions. The game is symmetric, as both players are assumed to know that they have the same utility functions (U_{crash}, U_T), hence they both have the same optimal strategies. These optimal strategies are derivable from game theory together with meta-strategy convergence, via recursion. Sequential Chicken can be viewed as a sequence of one-shot sub-games, whose payoffs are the expected values of new games resulting from the actions, and are solvable by standard game theory.

The (discretized) locations of the players can be represented by (y,x,t) at turn t and their actions $a_Y, a_X \in \{1,2\}$ for speed selection. The new state at turn $t+1$ is given by $(y+a_Y, x+a_X, t+1)$. Define $v_{y,x,t} = (v^Y_{y,x,t}, v^X_{y,x,t})$ as the value (expected utility, assuming all players play optimally) of the game for state (y,x,t). As in standard game theory the value

[1] Institute for Transport Studies (ITS), University of Leeds, UK
[2] Lincoln Centre for Autonomous Systems (LCAS), School of Computer Science, University of Lincoln, UK
[3] Ibex Automation Ltd, UK
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of each 2×2 payoff matrix can then be written as,

$$v_{y,x,t} = v(\begin{bmatrix} v(y-1,x-1,t+1) & v(y-1,x-2,t+1) \\ v(y-2,x-1,t+1) & v(y-2,x-2,t+1) \end{bmatrix}), \quad (1)$$

which can be solved using dynamic programming assuming meta-strategy convergence equilibrium selection. Under some approximations based on the temporal gauge invariance described in [3], we may remove the dependencies on the time t in our implementation so that only the locations (y,x) are required in computation of $v_{y,x}$ and optimal strategy selection.

Virtual Reality (VR) offers the opportunity to experiment on human behaviour in similated real world environments that can be dangerous or difficult to study, such as pedestrian road crossing. The present study uses VR to run the game thereotic model on a virtual autonomous vehicle and then examines the responses of human participants to that.

Contributions: To our best knowledge, this is the first attempt to evaluate pedestrian behaviour during interaction scenarios with a game theoretic autonomous vehicle in a virtual reality environment. It examines pedestrian road-crossing preferences (U_{crash}, U_T) when interacting with the virtual autonomous vehicle and demonstrates the importance of VR for the development of the model.

II. Related Work

There are few previous studies which investigated on interactions between autonomous vehicles and other road users in VR. Wang et al. [7] developed 5 different behaviours for an autonomous vehicle. The vehicle behaviour was successfully tested in different simulated traffic scenarios such as at intersections and lane changing, in a simulated city and highway road networks. Keferböck et al. [5] studied autonomous vehicles interactions with pedestrians in a virtual environment. In one of their experiments, participants are asked to cross a road in front of them while a car is approaching. This experiment differs from ours in that the AV stops and shows (or not) a stop intent to pedestrians. This study aimed to show the importance of substituting communications between pedestrians and drivers by some explicit communication forms for self-driving cars. Pillai [6] used task analysis to divide pedestrian-vehicle interaction as a sequence of actions giving two outcomes, either the vehicle passes first or the pedestrian crosses and perform some experiments with participants on their crossing behavior using virtual reality. Hartmann et al. [4] proposed a tesing procedure of pedestrian collision avoidance for autonomous vehicles using VR techniques. This test bed can take into account different factors that could influence pedestrian behaviour such as their understanding of the environment, their body movement and their personality.

We previously performed laboratory experiments to fit data to the game theory model [3]. We first asked participants to play this game as a board game in [2]. Secondly, participants were asked to play the game in person moving on squares [1]. These previous laboratory experiments have shown unrealistic results, participants preferring time saving rather than collision avoidance. The present study aims to extend these experiments and put participants in more realistic interaction scenarios with a game theoretic autonomous vehicle in a virtual environment.

III. Methods

A. 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 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.

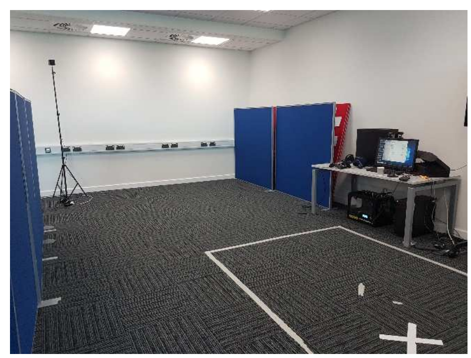

Fig. 3: VR Lab

B. Car behaviour model

The virtual AV 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 was designed not to stop for any pedestrian. 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. 4: Virtual Autonomous Vehicle

C. *Human experiment*

We invited 11 participants, 10 males and 1 female aged between 19 and 37 years old, to take part to the study, under University of Lincoln Research Ethics. 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, when they reached a yellow cube, located there for safety reasons. A vehicle approaches from their right hand side. Participants began walking about 4 meters away from the intersection. Prior to the experiment, participants were introduced to the experimental setup and trained on walking within the VR environment with the VR headset. There were 6 trials per participants in the virtual environment with the first trials considered as training data.

Fig. 5: Participant taking part in the study

IV. Results

In total, 55 pedestrian-vehicle interactions were recorded. Among those interactions, pedestrians managed to cross the road before the car reached the intersection only 9 times. These crossings happened after the first trials, by pedestrians who felt confident after evaluting/gauging the car driving style. Most interactions looked similar to Fig. 6, which shows the trajectories of a participant and the autonomous vehicle during one interaction. The trajectory profile shows that pedestrians were slowing down very quickly after seeing the car, they were not playing optimally the game of chicken, so that the AV could cross most of the time.

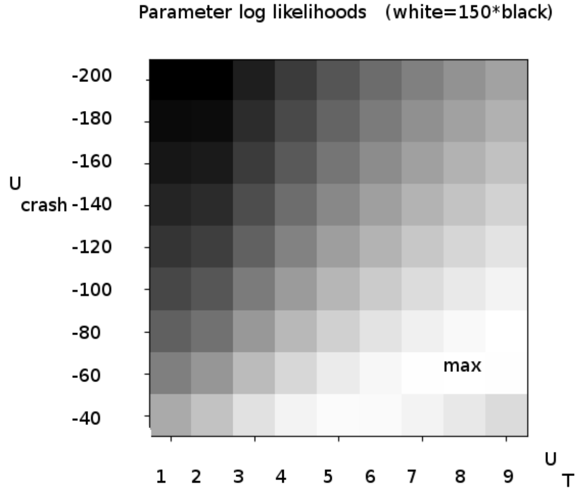

Fig. 7: Pedestrian behaviour preference

Similar to the optimal solution computation method developed in the laboratory experiments [2] [1], we obtain an optimal parameter, $\theta = U_{crash}/U_T = -60/8 = 7.5$, for participants, as shown in Fig. 7. This reveals that pedestrians valued avoidance of a crash 8 times more more than a 0.02s time saving per turn, resulting in pedestrians being less assertive in crossing the road. In comparison, previous laboratory experiments found that participants valued time saving more than collision avoidance [2][1].

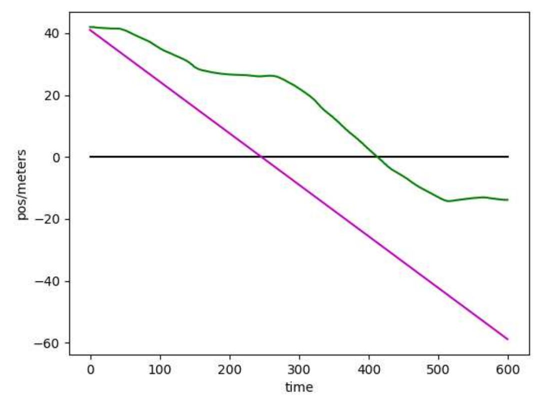

Fig. 6: Example of pedestrian and AV trajectories (magenta: AV; green: pedestrian)

V. Conclusion

The present study demonstrated a work-in progress on the use of virtual reality for the development of game theoretic AV controllers. We examined the trajectories of pedestrians interacting with a virtual autonomous vehicle which makes its decisions based on the sequential chicken model. The results reveal that pedestrian behaviour is more natural in VR than in previous laboratory experiments. This is important, as it shows that virtual reality makes pedestrian crossing behaviour more realistic and it can therefore help improve the development of the game theorectic model. Future work would include the evaluation of pedestrian crossing behaviours with different car models and within different environments. Methods of learning the best behaviour parameters for the autonomous vehicle will be explored in future VR studies.

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