I, AV: A Ghost Driver Field Study Exploring the Application of Anthropomorphism in AV-Pedestrian Communication

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ABSTRACT

We employed the 'Ghost Driver' methodology to emulate an autonomous vehicle (AV) and explored pedestrians' (n=520) crossing behaviour in response to external human-machine interfaces (eHMIs). Three eHMI designs were created to replace absent pedestrian-driver communication; each had different anthropomorphic elements and were identified as 'explicit', 'implicit' and 'low' to reflect the conspicuity of anthropomorphism. They were displayed on an LED matrix and strip mounted to the front of a Nissan Leaf vehicle, which was driven around the University campus over 5 days. Video analysis highlighted differences in pedestrians' behaviour, with the explicit anthropomorphism eHMI extending crossing time and attracting more visual attention. Additionally, some pedestrians continued to use gestures, ostensibly to indicate their intention to cross or to thank the vehicle, despite the absence of a visible driver. While preliminary findings support the application of anthropomorphism in AV-pedestrian communications, further research will explore designs in more controlled, experimental settings.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Empirical studies in HCI.

KEYWORDS

Ghost Driver, eHMI, Anthropomorphism, Pedestrian, Vulnerable Road User

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1 INTRODUCTION

There has been considerable interest in the potential impact of highly and fully autonomous ('self-driving') vehicles (AVs) on the behaviour of vulnerable road users, especially pedestrians. Such vehicles, operating at SAE level 4 or 5 are unlikely to have a human driver onboard. As such, a plethora of non-verbal (head, eye, hand/arm gestures etc.), and occasional verbal, cues, that are traditionally exchanged between a driver and a pedestrian, will be absent. These traditionally aim to establish a mutual understanding of perception (*I have seen you*), approach intent (*I am giving way*) and leave intent (*I am about to set off again*) [1]. Whilst it is recognised that in many situations the dominant cues processed by a pedestrian are the vehicle's approach speed and deceleration profile (so-called implicit cues; [2]), it is also acknowledged that pedestrian-driver social negotiations (explicit cues) are important to overall traffic safety, especially in low-speed crossing scenarios in complex urban settings [3]. For example, Lee et al. [4] reported that 27% of pedestrians made eye contact with the driver while crossing the road. Moreover, it is anticipated that explicit communication from an AV to pedestrians will be important to secure underlying confidence and trust in AVs, following the widescale introduction of such vehicles [5].

1.1 External Human-Machine Interfaces (eHMIs)

There has been much debate regarding how an AV could provide information to pedestrians (and indeed, other road users) in order for them to make appropriate decisions regarding their movements on the road, for example, when to cross. A number of different external human-machine interface (e-HMI) concepts have thus been proposed, utilising various modalities and levels of complexity [6, 7]. However, although there is work underway to develop an international standard in this area[1], there is currently no consensus on an ideal solution. The majority of existing eHMI design concepts utilise visual modalities (e.g., text, light or colour) to communicate with pedestrians, although auditory and haptic interfaces have also been posited. Nevertheless, many of the proposed concepts are untested. Where empirical research has taken place, it has tended

[1]ISO/AWI PAS 23735 Available online: https://www.iso.org/standard/77988.html (Accessed: 25 May 2023)

to use immersive virtual reality (VR) as an experimental method to compare different e-HMI concepts and understand how pedestrians might respond to an AV in highly defined experimental scenarios [8]. Using VR as a methodological approach is understandable, partly as AVs do not presently exist on UK roads (at least, not outside of controlled trials), but also as it provides control and minimises confounding variables. Nevertheless, it is cautioned that although certain elements may feature highly in eHMI concepts and/or perform well in VR evaluations, it does not necessarily follow that they are the most effective and accessible means of communication with vulnerable road users in real-world crossing scenarios.

1.2 Anthropomorphism

A common proposition in driving-related works is the inclusion of 'human' elements or mannerisms (so-called anthropomorphism) within vehicle and interface design. Indeed, anthropomorphism has been shown to aid understanding, acceptance and trust in AVs generally [9]. For example, people who used an anthropomorphised AV (vehicle given a name, gender and humanlike voice) were more trusting of the vehicle and were less likely to allocate blame to it following an accident, compared with an AV absent of these features [10]. Similarly, a humanlike 'conversational' interface was rated more highly by users for trust, perceived intelligence etc. than a graphical user interface [11] and, additionally, enabled a more pleasurable experience in an AV pod [12]. It is therefore posited that similar benefits (in terms of enhanced understanding, trust, acceptance etc.) may be forthcoming for indirect users of AVs, such as a pedestrian who incidentally encounters the vehicle, by incorporating anthropomorphism within the design of external interfaces.

1.3 Ghost Driver

Over recent years, there have been several high-profile studies which have utilised a Wizard-of-Oz (WoZ) approach to simulate an AV [13–15]. In these on-road studies, the so-called 'Ghost Driver' [13] is typically concealed within a bespoke seat-suit thereby ensuring they cannot be seen by pedestrians and other road users if they make a cursory glance. Such an approach provides high ecological validity, enabling researchers to understand how pedestrians might naturally behave when faced with a 'genuine' driverless vehicle in real-world crossing/traffic scenarios.

These studies have revealed hesitancy in crossing and pedestrians 'playing' with the car to test sensor capabilities [14]. Nevertheless, pedestrians have also expressed difficulty interpreting the behaviour of the vehicle [15], and reported feeling less safe, and 'doubtful' about their interaction with the AV [16]. In addition, new and unexpected behavioural patterns have emerged in response to AVs, such as aggression and 'griefing' towards the vehicle [17]. However, this research has primarily occurred in the US/North America. Consequently, there is a lack of understanding regarding how pedestrians and other road users might behave in response an AV in other cultural contexts, where factors such as road infrastructure, social norms, risk perception, prevailing trust relationships, and so on, differ. In addition, to date, only one of the aforementioned WoZ studies has specifically considered how pedestrians might respond to an eHMI indicating intent [18]. Therefore, there is a sparsity of knowledge regarding how pedestrians behave in response to different eHMIs in real-traffic situations. The current research subsequently aims to explore the following research questions:

1. How do pedestrians in a UK cultural context naturally behave in response to an AV?
2. How does the design of the eHMI influence their behaviour?
3. How does anthropomorphism affect AV-pedestrian communication?

2 METHOD

2.1 eHMI Designs

A 'Ghost Driver' WoZ study was devised in which the driver/researcher was hidden in a bespoke seat-suit, thereby giving the appearance that the vehicle (a Nissan Leaf) was driving by itself (Figure 1).

Three eHMI designs were created. Designs were informed by the literature and prototyped using an individually addressable RGB-LED matrix and strip attached to the outside of the vehicle (on the front of the bonnet and top of the windscreen, respectively) (Figure 2). A "blue-green" colour was selected for all elements (see: [19]). The LEDs were controlled by an Arduino Mega board and push-button controls, manipulated by a second researcher located within the vehicle. The eHMI designs employed varying degrees of anthropomorphism, notionally described as Explicit, Implicit and Low to reflect the conspicuity of human elements. Explicit was so-named as it included explicitly recognisable 'human' elements and mannerisms, i.e. a face and 'first person' speech. The Implicit design included elements based on human attributes, but not necessarily immediately recognisable as such (e.g., a light cluster moving from side to side intended to represent a single eye scanning the road ahead). The Low design primarily utilised non-human elements, such as a car icon. For each design, four states were created: scanning, giving way (pedestrian/s on right), giving way (pedestrian/s on left) and giving way (pedestrian/s on both sides of road).

The Explicit Anthropomorphism eHMI utilised both the LED strip and the matrix. The matrix displayed elements of a face/persona (affectionately named 'Hathaway', after the titular character in the anime film[2]). Hathaway's mouth, eyebrows, eyes and pupils adopted natural human behaviours, for example, the eyes moved side-to-side to look/scan (Figure 3). If a pedestrian waiting to cross the road was detected, the eyes paused at the appropriate side of the vehicle, and the face then smiled and 'spoke' via written text to inform the pedestrian *"I am giving way"* (presented in a speech bubble/balloon) (Figure 3). If pedestrians were on both sides of the road, the eyes and spoken text were presented on each side, in turn. The LED strip remained fully illuminated throughout to indicate autonomous/scanning mode (Figure 2).

The Implicit Anthropomorphism eHMI utilised the LED strip to mimic the pupillary response of an eye. The 'mono-eye' moved from side-to-side to represent looking/scanning (Figure 2). If a pedestrian waiting to cross the road was detected, the mono-eye paused at the

[2] Mobile Suit Gundam Hathaway. https://gundam.fandom.com/wiki/Mobile_Suit_Gundam_Hathaway (Accessed: 23 May 2023)

Figure 1: Driver in seat suit, aka 'Ghost Driver' [13]

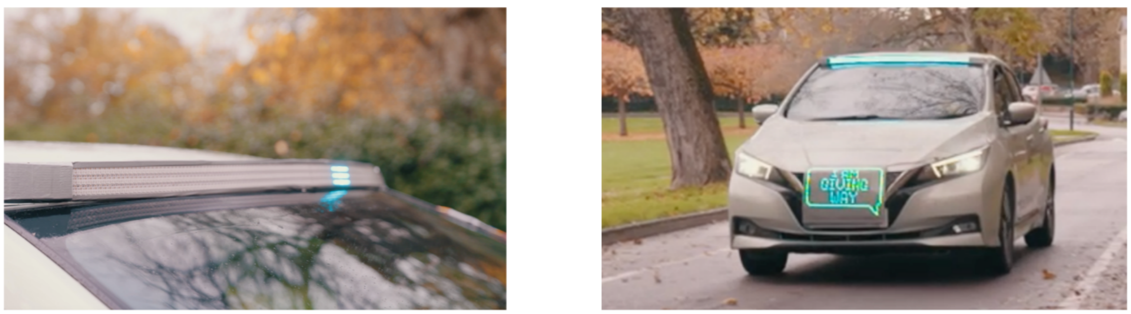

Figure 2: LED Strip Design showing Implicit Anthro. mono-eye *scanning* (L) and location of LED matrix and strip on vehicle (Explicit Anthro. design with strip fully illuminated) (R)

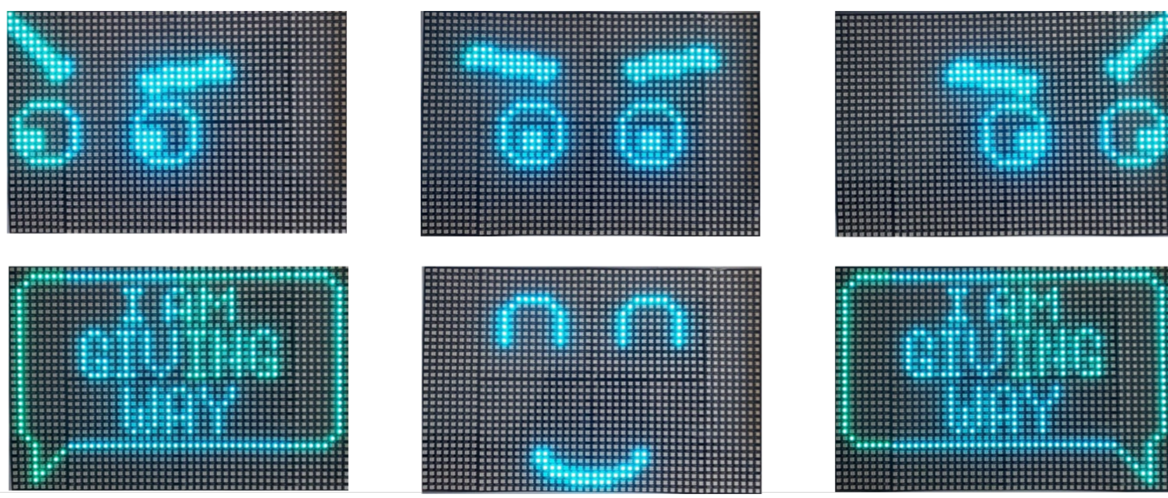

Figure 3: Example LED Matrix Designs showing (top) Explicit Anthro. *Scanning* (i.e., looking left, looking ahead, looking right) (Note: messages cycled between all 3 states) and (bottom) *Giving Way* (pedestrian on left, smiley face ("I see you"), pedestrian on right) (Note: messages cycled between smiley face and, either, give way to left or give way to right, as appropriate)

appropriate side of the road and constricted to indicate that the vehicle's attention has been drawn (if pedestrians were present on both sides, the mono-eye behaved in this manner on each side, in turn). Subsequent blinking of the mono-eye provided an implicit cue that the vehicle was giving way. Blinking rate was designed to transmit "I, AV" in Morse code (i.e., the vehicle referred to itself using the first person to demonstrate self-awareness).

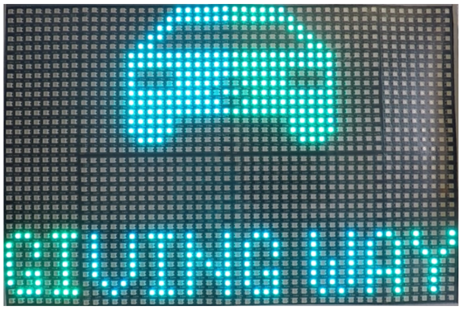

Figure 4: LED Matrix Design showing Low Anthro. *Giving Way* (Note: this was accompanied by the LED strip 'mono-eye')

The Low Anthropomorphism eHMI utilised both the LED strip and matrix. The 'mono-eye' moved from side-to-side and acted in the same manner as for the implicit anthropomorphism (Figure 2). When a pedestrian was detected, the matrix displayed a car icon followed by text ('[CAR] giving way') (Figure 4). The mono-eye corresponded with the matrix interface to indicate the side of the road on which the pedestrian had been observed.

2.2 Procedure and Data Capture

The car was driven in a 'defensive' driving style (smooth acceleration and braking, cautious speed selection etc.) around a designated, circular route on the University of Nottingham (UoN) campus that included several marked 'zebra' crossings and several unmarked (but commonly used) crossing points. Data were collected over 5 days, with the vehicle travelling the same distance (i.e., same number of circuits of the route) while displaying each eHMI. A fourth, baseline condition (no eHMI) was also evaluated. All eHMIs were evaluated on each of the 5 days. The current state of the eHMI (scanning, giving way etc.) was determined by the second researcher located in the rear of the ego-vehicle in response to the behaviour and proximity of any observable pedestrians in the vicinity of the vehicle as it approached each crossing. Between crossings, the relevant scanning mode was displayed. Video data were captured using GoPro recorders to document pedestrians' responses to the 'driverless' vehicle and different eHMIs. The study design was approved by the UoN Faculty of Engineering ethics committee.

3 RESULTS

We present preliminary findings from video content analysis of pedestrians (n=520) who encountered the vehicle. In total, 130 minutes of video data were coded using BORIS software [20] (approximately 32mins per eHMI/condition) (Figure 5). The coding scheme was inspired by literature [21]. Additional coding elements were added based on the emergence of new, relevant crossing behaviours. Codes included pedestrians' crossing behaviour (start/stop crossing, individual/in group, speed maintenance, cross location and direction), gestures (wave, glance, stare), distractions (e.g., using phone) and vehicle behaviour (car moving, slowing, stopped). Crossing Time (CT) and Glance Time (GT) were determined from the coded video data and related timestamps. ANOVAs indicate statistically significant differences for both CT and GT (p = .041 and p < .001, respectively) (Figure 6). Pairwise comparisons show that pedestrians took longer to cross the road when presented with the Explicit eHMI (M=8.5s, SD=2.0s) compared to the Low eHMI (M=8.0s, SD=1.9s) (p = .020) and No eHMI (M=7.6s, SD=1.9s) (p = .004). Additionally, the duration of glances to the eHMI/vehicle were longer for the Explicit eHMI (M=2.9s, SD=2.6s) compared to Low (M=2.3s, SD=2.1s) (p = .040), Implicit (M=1.9s, SD= 1.6s) (p = .002), and No eHMI (M=1.9s, SD=1.7s) (p < .001). Cumulatively, over 12% (n=63) of crossing pedestrians continued to use hand gestures, ostensibly to indicate their intention to cross the road (i.e. before stepping onto road) or to thank the 'vehicle' (during the crossing). There was a higher relative occurrence of gestures noted during the Low Anthropomorphism (18.3% of pedestrians) and Implicit eHMIs (21.6%), compared to the Explicit and no eHMI (both 9.1%).

4 DISCUSSION

This exploratory study was conceived to investigate pedestrians' behaviours in response to AV-eHMIs. However, studying naturalistic behaviours of people responding to AVs presents a number of challenges. Indeed, there are limited trials of such technology on public roads, and, as it currently stands in the UK, any on-road AV trial requires a safety driver to be present in the driver's seat, thus negating the true impact of the driverless technology when pedestrians encounter the vehicle. In contrast, highly controlled experimental studies delivered using immersive VR arguably lack ecological validity. By concealing the driver within the seat (aka Ghost Driver [13]) and capturing incidental encounters with the vehicle over five days, we were able to observe naturalistic behaviour in response to an AV, evaluate prototype eHMIs and explore the value of anthropomorphism in their design.

Initial results show that the Explicit Anthro. eHMI captured the most visual attention. During the study, this manifested as longer crossing time and multiple/longer glances. While caution should be applied (in terms of minimising the time pedestrians spend on the roadway while crossing), capturing a pedestrian's attention is an important first stage of communicating with them, and techniques to do so quickly and effectively should be explored further. Nevertheless, techniques to expedite crossing time (once the decision is made and it is safe to do so) should also be explored.

People also responded positively to the Explicit Anthro. eHMI (based on observations and field notes made by the researchers involved in the study), for example, by smiling and laughing. This supports the potential for an eHMI to provide a positive user experience for pedestrians interacting with an AV. Furthermore, the general proclivity to continue to use hand gestures suggests an expectation of social, human elements during the interaction, thereby supporting the inclusion and application of anthropomorphism within the design of eHMIs. Nevertheless, it remains unclear if pedestrians who 'thanked' the vehicle with a hand gesture or wave, were acknowledging the AV itself or responding instinctively, based on their expectation ('mental model') of a human driver present in the vehicle.

The study was conceived to explore naturalistic behaviours of pedestrians in response to eHMIs on the road, and while every

Figure 5: Example screenshots captured from the GoPro camera, showing pedestrian taking photo (left) and pedestrian thanking vehicle with wave (right).

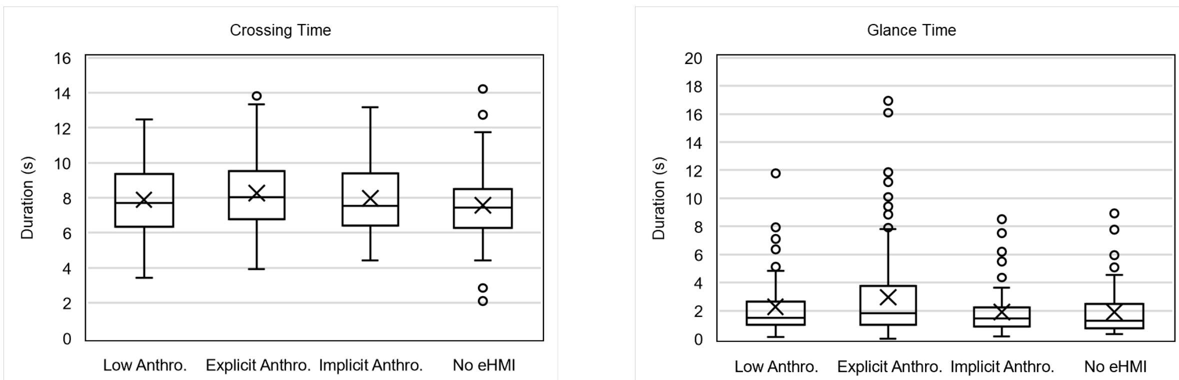

Figure 6: Boxplots showing Differences in Crossing Time (L) and Glance Time (R)

effort was made to balance the groups (i.e., by controlling exposure time/number of circuits driven), the number of participants experiencing each eHMI ultimately differed. This is a limiting factor of any naturalistic, evaluation study, and only becomes truly apparent during post-hoc analysis. Moreover, the natural behaviour of pedestrians meant that each person potentially experienced the eHMI in a slightly different manner (e.g., approaching the crossing, already at the roadside, with others in a group etc.). Although we documented these differences in the video coding, certain metrics, such as hesitancy (and the implied trust formation), are difficult to accurately extract from the data. For example, pedestrians who were already at the roadside when they first encountered the eHMI and/or AV, and subsequently delayed their crossing while they made judgements about trust, confidence etc., may be deemed to be hesitant/waiting, whereas other pedestrians may have made these judgements as they approached the crossing; for approaching pedestrians, any hesitancy or delay would not necessarily be apparent.

Finally, the study, by definition, presented a novel situation, and many people would not have encountered a driverless vehicle previously or indeed, an external HMI. Whilst general awareness of driverless vehicles as a concept may be more common than say in 2016, when the original Ghost Driver study was conducted, there may still have been surprised and/or scepticism associated with the encounter. This may have unnaturally increased the number and/or duration of glances directed to the vehicle (though this would be true for all conditions). It is also noted that glances may not necessarily have been directed solely to the eHMI, as our reporting may indicate. Nevertheless, we would argue that in the context of the study, all glances directed to the vehicle are of value in terms of increasing awareness of its presence and understanding its behaviour, as our eHMIs were designed to do.

5 CONCLUSION

As an exploratory field study, the research has provided some valuable, initial insights into the application of anthropomorphism in AV-pedestrian communication, with results suggesting that the inclusion of human elements and mannerisms within the design of eHMIs may help to gain pedestrians' attention and has the potential to provide a positive user experience. Moreover, the study contributes to the body of work showcasing the Ghost Driver method as a reliable and robust approach to capture pedestrians' genuine interactions with an AV. Nevertheless, further work should now seek to explore eHMI designs in a more controlled, experimental manner (considering recognised factors such as trust, acceptance, message clarity etc.), with the aim of aiding trust formation and contributing to safer crossing practices when encountering an AV.

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