Can Interfaces Facilitate Communication in Autonomous Vehicle-Pedestrian Interaction?

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ABSTRACT

Current vehicle-pedestrian interactions involve the vehicle communicating cues through its physical movement and through nonverbal cues from the driver. Our work studies vehicle-pedestrian interactions at a crosswalk in the presence of autonomous vehicles (without a driver) facilitated by the deployment of interfaces intended to replace missing driver cues. We created four prototype interfaces based on different modalities (such as visual, auditory, and physical) and locations (on the vehicle, on street infrastructure, on the pedestrian, or on a combination of the vehicle, street infrastructure, and the pedestrian). Our findings from two user studies indicate that interfaces which communicate awareness and intent can help pedestrians attempting to cross. We also find that interfaces are not limited to existing only on the vehicle.

KEYWORDS

Autonomous Vehicle-Pedestrian Interaction

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1 INTRODUCTION

Vehicles provide information on their awareness and intent of pedestrians using movement patterns such as speed, acceleration, and stopping distance [6]. Pedestrians also receive nonverbal cues from the driver through facial expression, eye gaze and contact, gestures and body movement, and possibly voice and tone of speech [2, 8, 9]. These cues reassure the pedestrian about the driver's awareness and the imminent vehicle's actions.

In the short term, vehicle-pedestrian interactions are expected to become complex. With the introduction of vehicles with varying levels of autonomy, pedestrians would be interacting with manually-driven vehicles, semi-autonomous vehicles, and completely autonomous vehicles. While it is expected that manually-driven vehicles will continue providing driver cues, completely autonomous vehicles will not provide them (given there is no driver).

Recent work suggests that perhaps autonomous vehicles may not need to provide driver cues, and can communicate with the majority of pedestrians using physical movement alone [7]. In contrast, other recent findings have also shown that the loss of driver cues decrease the pedestrian's confidence [4] and trust [5].

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We explore the role of interfaces that explicitly communicate the awareness and intent of an autonomous vehicle in helping pedestrians make crossing decisions. In this paper, we define the *communication of awareness* as the vehicle's ability to acknowledge the pedestrian's presence and the *communication of intent* as the vehicle's ability to communicate its next action to the pedestrian (such as about to stop for the pedestrian). We deployed four prototypes based on a design space outlining plausible locations where an interface could lie, namely: (i) Vehicle-Only - interfaces that reside on the vehicle, (ii) Vehicle and Street Infrastructure - interfaces that reside on the vehicle and on street infrastructure, (iii) Vehicle and Pedestrian - interfaces that lie on the vehicle and on the pedestrian, and (iv) Mixed - interfaces that reside in conjunction with the vehicle, street infrastructure, and the pedestrian. We assessed these prototypes through two user studies on a Segway and a car.

2 RELATED WORK

There have been a few contributions proposing interfaces for autonomous vehicles. Lagström and Lundgren placed an LED strip on the windshield of a car (which communicate intent to pedestrians) and found it effective in helping pedestrians make crossing decisions [3, 4]. However, a more recent field study by Clamann et al. [1] shows mixed results. They designed and mounted a display on a vehicle, which communicated intent cues in two ways: (i) through the road symbols "cross" or "don't cross", and (ii) an information display showing the speed of the vehicle. Their study revealed that gap distance and crossing strategies which pedestrians had developed over time influenced crossing decisions more than the display. Currently, there is no consensus on whether interfaces are a necessity for autonomous vehicle-pedestrian interactions.

Our work attempts to make two contributions. First, we explore whether interfaces that communicate both awareness and intent can help autonomous vehicle-pedestrian interactions by supporting pedestrians' crossing decisions. We also explore where these interfaces can reside.

3 CURRENT WORK

We ran two user studies, one on a Segway, and another on a car. We conducted the Segway study in a corridor of a building, and the car study in a closed off parking lot. We opted to use a Segway as it could be teleoperated to appear autonomous to participants. However, because the Segway is a small vehicle, we also conducted a study on a car to counteract possible confound arising from its harmless profile. We recruited ten participants for each study (total of 20). We deployed prototypes from each of the aforementioned categories of interfaces, as Figure 1 shows. Given the design space for interface design is vast, we built a subset of prototype instances. For each interface, we included at least one awareness and one intent cue, and a mix of visual, auditory, and physical cue modalities.

In both studies, participants were asked to make crossing decisions in the presence of a vehicle which we informed them was autonomous. However, it was operated by a researcher at all times

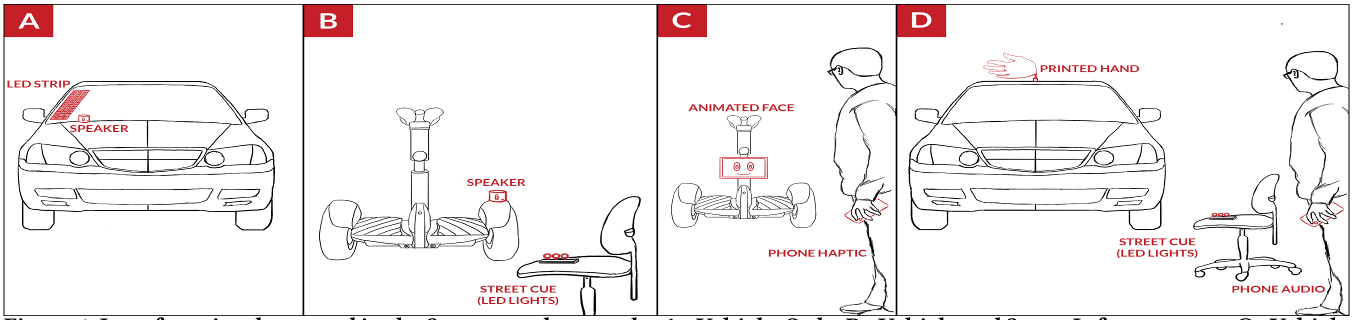

Figure 1: Interfaces implemented in the Segway and car study: A - Vehicle-Only, B - Vehicle and Street Infrastructure, C - Vehicle and Pedestrian, D - Mixed. Elements in red indicate the cues we deployed in each interface.

(through Wizard-of-Oz). In total, there 5 tasks (baseline and four interfaces) x 2 trials (stop and not stop) giving a total of 10 trials for each platform. In each study, participants first saw the "no interface" task, where the vehicle's movement was the only cue to interpret its awareness and intent. Next, participants saw each of the four interfaces shown in Figure 1 in random order. In addition, each task involved two trials, one where the vehicle stopped, and another where the vehicle did not stop, and these were randomized. The vehicle was operated at a consistent speed across both platforms and trials. We collected feedback from each participant through five-point Likert scale questions and an interview we conducted.

4 RESULTS AND DISCUSSION

We found that all participants found communicating awareness and intent cues to be important through responses to two five-point Likert scale questions. However, communicating intent was deemed more important than communicating awareness by 6 out of 10 participants in the Segway study, and by 7 out of 10 participants in the car study. In interviews, participants stated that communicating awareness did not suffice. In a traditional vehicle-pedestrian interaction, the awareness of a pedestrian does not guarantee that the driver of a vehicle will stop (for example, at an uncontrolled intersection). Pedestrians' prior crossing experience in the presence of manually-driven vehicles could explain why the communication of intent remains more crucial for autonomous vehicles. We suggest that interfaces can be considered "training wheels" through which pedestrians can learn to interact with autonomous vehicles as they are introduced. Over time, such interactions could become second-nature, and then interfaces may not be necessary.

Further, when we asked participants to rank the four prototypes' effectiveness in helping them cross, the most effective interface differed between platforms. In the Segway study, 6 out of 10 participants chose the mixed interface (Figure 1D) to be the most effective. In the car study, 5 out of 10 participants chose the vehicle and street infrastructure interface (Figure 1B) to be the most effective. This implies that interfaces can reside on and off the vehicle, since both interfaces that participants chose to be most effective included elements on the vehicle and external to it.

When we asked participants about the effectiveness of cues external to the vehicle, reliability was their most important consideration. This was especially evident when we asked them to compare auditory cues, one from a speaker shown in Figure 1A and Figure 1B, to phone audio from Figure 1D. In the car study, 4 out of 10 participants expressed that they preferred hearing auditory cues about the vehicle's state from the vehicle. A possible explanation is that they believe the audio message is tied to the vehicle's operation since it emanates from the "source" as opposed to a "third-party". Yet, 5 out of 10 participants preferred hearing auditory cues about the vehicle's state from a phone next to them because they felt it was more practical in the real world (as sounds projecting from a speaker on the vehicle would be more affected by external entities such as background noise, distance to the pedestrian, and a cacophony resulting from multiple vehicles playing the same message).

This implies a shift in the way we perceive the communication between a vehicle and a pedestrian. Current vehicle-pedestrian interactions focus on communication primarily from the vehicle (and the driver, an entity also a part of the vehicle), and sometimes from static infrastructure (when at controlled intersections with traffic lights and pedestrian walk signals). In the case of autonomous vehicles, interface elements can also rely on mobile technology and still be perceived as effective and reliable by pedestrians.

5 CONCLUSIONS AND FUTURE WORK

Through our work, we found that interfaces which communicate awareness and intent can assist pedestrians in making crossing decisions in the presence of autonomous vehicles. Further, we also found that interface elements can lie external to the vehicle and remain effective in communicating the vehicle's awareness and intent reliably. We would like to conduct experiments with multiple vehicles and pedestrians where we predict that scalability will become a relevant constraint. Some ideas for overcoming this challenge include the creation of a synchronization protocol to handle the transmission of cues between several vehicles and pedestrians.

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