Enabling Pedestrian Communication with Autonomous Vehicles

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Abstract
Current vehicle-pedestrian interactions invoke informal communication between pedestrians and drivers. However, with the introduction of autonomous vehicles without a driver on board, pedestrian interaction will be limited to interaction with the vehicle. We suggest that new interaction paradigms have to be considered for autonomous vehicle-pedestrian interaction. In this paper, we discuss the challenges associated with pedestrians who will be interacting with a combination of manually-driven, semi-autonomous and fully autonomous vehicles in the near future.

Author Keywords
Autonomous vehicle-pedestrian interaction; explicit pedestrian communication with autonomous vehicles.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous; I.2.9 [Robotics]: Autonomous vehicles.

Introduction
Autonomous vehicles are expected to become an integral part of our society upon their introduction. They will free us of the responsibility to drive safely by taking the wheel, but also save us valuable time in the process. As these vehicles become prevalent in our streets, pedestrians will be interacting with them along with vehicles of lower levels of

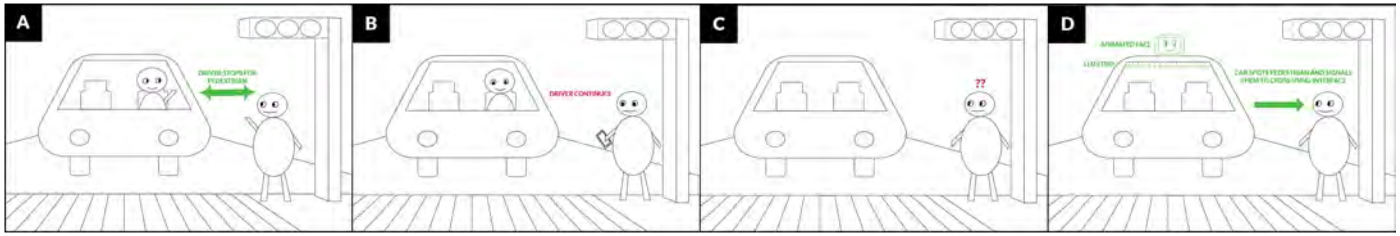

Figure 1: Interactions of Pedestrians with Vehicles, where - A: bidirectional communication channel exists between driver and pedestrian, B: driver knows pedestrian doesn't want to cross as they don't exchange informal cues, C: pedestrian is unable to tell what the autonomous vehicle is about to do and vice versa, D: autonomous vehicle communicates to the pedestrian using interfaces through unidirectional communication.

autonomy. We will eventually reach a state where all vehicles on the road are autonomous, but this will take place gradually. Figure 1A shows the typical interaction between a driver of a manually-driven vehicle and a pedestrian. Here, both parties are able to communicate with each other through informal communication cues such as eye contact and hand gestures. However, because fully autonomous vehicles will not have a driver on board, they will not provide informal cues that pedestrians are used to receiving when making crossing decisions (including but not limited to eye contact, body gestures, and possibly voice). Instead, pedestrians will only have motion cues originating from the vehicle to aid them in the decision making process, as Figure 1C illustrates.

Our recent work has shown that interfaces located both on the vehicle and in the outside environment (i.e. integrated into street infrastructure and pedestrians' devices) can help address the lack of driver-provided cues in autonomous vehicles [3]. Further, we found that when interfaces are used in conjunction with an autonomous vehicle's motion, they can assist pedestrians in making crossing decisions. Figure 1D highlights one such scenario.

While our previous work explores the explicit communication of vehicle information to a pedestrian, this is a unidirectional channel of communication. Ideally, we would like to obtain two-way communication between autonomous vehicles and pedestrians. For instance, in a traditional scenario, pedestrians standing near a crosswalk but not intending to cross, can simply signal this to the driver to prevent them from stopping. However, it is unclear how such an interaction would look if a pedestrian had to communicate the same information to an autonomous vehicle.

The benefits of autonomous vehicles will not be fully realized unless there is a well-established bidirectional communication channel between autonomous vehicles and pedestrians. In this paper, we explore possible ways to handle pedestrian interaction with autonomous vehicles.

Interaction Based on Level of Autonomy

We think that as the extent of autonomy on our streets increases through the introduction of vehicles with varying levels of autonomy, pedestrians will interact with them through different mechanisms.

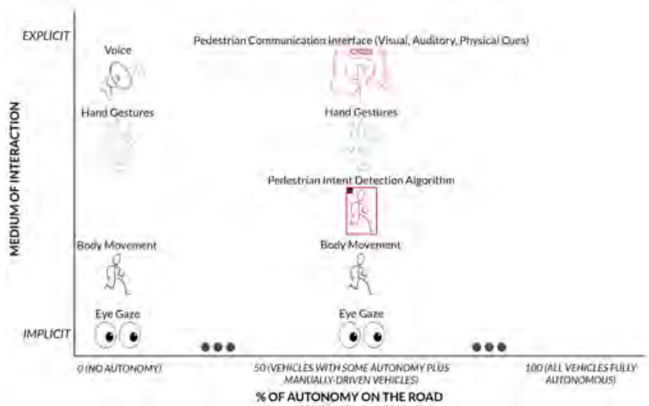

Figure 2: Mediums of interaction that a pedestrian can use for vehicles with different levels of autonomous behavior.

No Autonomy

This is the current situation, where pedestrians communicate their next actions to drivers since they are in control of the vehicle. Schmidt and Färber [5] conducted an extensive study to assess what characteristics a driver of a manually-driven vehicle uses from the pedestrian to help them decide whether to stop at a crosswalk. They found that parameters of body language such as leg or head movements are most crucial in helping drivers predict a pedestrian's intent. Research has also shown that gaze is a powerful tool that pedestrians use to communicate to drivers that they would like to cross [1, 4]. Figure 2 portrays these informal communication mediums.

Mixed Autonomy

We think that as the first wave of autonomous vehicles appear on our streets, the challenges of vehicle-pedestrian interaction will become acute. First, there will be vehicles with varying levels of autonomy [1], some of which will still require a driver inside to perform tasks periodically. Next, as fully autonomous vehicles are introduced (level 5 in the NHTSA scale), they may or may not have passengers inside. In combination with manually-driven and semi-autonomous vehicles, this could present a dilemma for pedestrians since they will not know who is in control of any vehicle they see, especially during poor lighting or weather conditions. We assume there will be some mechanism to delineate manually-driven vehicles from autonomous vehicles, such as an led strip as posed in other work [2]. However, this may not be enough for pedestrians to quickly decipher who is in control especially when making split-second decisions such as crossing. As such, we think that pedestrians are likely going to continue employing similar informal cues as before, such as eye gaze, body movement, hand gestures, and perhaps even voice.

Although pedestrians will continue to use such cues, vehicles where the driver is not in control will still need to understand what the pedestrian is attempting to do. Autonomous vehicles currently being tested on our roads are being endowed with the ability to detect pedestrians and classify them as such. This is a challenging research problem in computer vision because pedestrians can be of different sizes especially if they are at varying distances away from the vehicle, but also because they can be occluded by other objects and poor lighting. Once found, vehicles then plan to avoid pedestrians by predicting their motion. Detecting pedestrians alone isn't sufficient, because pedestrians and drivers share rich informal communication that goes beyond the pedestrian's possible motion trajectories, and include subtle movements of the head and body, change in eye gaze, and gesturing. This information needs to be incorporated sufficiently well to allow pedestrians to communicate effectively with these vehicles. Both detection and pedestrian intent prediction are active research areas. Once such

[1] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

systems are in place, pedestrians can use familiar cues to communicate with human drivers and vehicles as both entities will then be able to understand them.

Intent prediction systems will gradually become proficient at identifying what pedestrians intend to do, but this may be a slow process. This is partially because research has shown that there is no such thing as an average pedestrian [6] and extrapolating the behavior of individuals from different driving cultures to build a unified behavioral model may be very difficult to achieve.

An alternative is introducing specialized interfaces to help pedestrians communicate their message to an autonomous vehicle. We would advocate prototyping and testing simple interfaces to assess whether pedestrians are comfortable with the idea of communicating their actions through an external interface. The interface could be as simple as pressing a button on a phone application as shown in Figure 2. However, we anticipate that pedestrians will then have to use two types of cues when they encounter both a manually-driven vehicle and an autonomous vehicle. When communicating with the former, pedestrians would use familiar cues such as eye gaze and gesture, but to inform the autonomous vehicle, they would need to send a signal using the phone application. This could pose problems of convenience and possibly cause confusion for pedestrians.

Full Autonomy

Eventually, over the course of a few decades, we imagine that all vehicles on the road will be autonomous. At this point, pedestrian interactions may become much simpler. First, it is entirely possible that street infrastructure of cities will change so pedestrians and vehicles will no longer share the same interaction space. As such, pedestrians will not have to interact with vehicles at all. If street infrastructure of the future remains the same, pedestrian intent detection systems at this stage could be proficient enough that pedestrians can communicate just as they used to with drivers of vehicles from the past. Finally, if such detection systems don't exist, a simple interface could be sufficient because all vehicles will be able to understand what a button press from the pedestrian would mean.

Conclusion and Future Work

Until a proficient pedestrian intent detection system is in place, we think that the mixed autonomy scenario will pose the most challenge to interaction designers for several reasons. First, pedestrians will need to communicate with human drivers and autonomous vehicles in a different manner. How should we keep pedestrians aware of which vehicles are in human control and which are not? Further, because semi-autonomous vehicles allow for a transfer of control to the human driver and vice versa, pedestrians will need to know if the transfer has happened instantaneously. Next, since we think pedestrians will need to communicate with autonomous vehicles more explicitly, how should we design simple interfaces that allow pedestrians to quickly communicate their actions to autonomous vehicles? Finally, how can such interfaces co-exist with informal communication cues pedestrians will exchange with human drivers especially when making split-second decisions? We hope that future research will attempt to address these issues.

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