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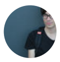

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A framework for designing interactions between pedestrians and driverless cars: Insights from a ride-sharing design study

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ABSTRACT

Previous work has highlighted the need for human factors research to not only focus on the passengers inside driverless cars but also consider others who will interact with the car in an urban environment such as pedestrians. In this paper, we position this area of research as a new opportunity for HCI and propose a framework to guide the design of the interactions between driverless cars and pedestrians. The framework draws on HCI literature and our findings from a design study, which focused on designing for the intent and awareness of driverless cars when picking up passengers in a ride-sharing scenario. We designed various interaction design proposals as mockups and tested their acceptance through three rounds of user evaluations. The framework was developed after the second evaluation round and was then applied to revise our design solutions and used in the final evaluation round. The framework offers guidance for breaking down use cases into stages of interactions, specifying the information channels and the interactions between driverless cars and pedestrians, as well as reflecting on how well each solution addresses the user needs.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Interaction design**;

KEYWORDS

Driverless cars, autonomous vehicles, pedestrians, virtual reality, prototyping, designing interactions

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1 INTRODUCTION

Driverless cars have the potential to not only change the way we travel but will also have significant implications on the urban environment such as the behaviour of pedestrians around vehicles. Currently, people use eye contact, gestures and other cues to negotiate between pedestrians and drivers [7]. The design of driverless cars will need to consider mechanisms for replacing inter-personal communication with means for the driverless car to communicate their intent to pedestrians in its vicinity. The car industry has recognised this need, linking communicating what the car can see to people around it with developing a sense of trust, for example, when crossing the road in front of a driverless car [9]. Previous work has recognised the importance of trust, suggesting that system transparency can increase trust in autonomous vehicles [15, 21]. Communicating a driverless vehicle's intent further affects the behaviour of pedestrians in a way that makes a car's behaviour more predictable [10].

Car manufacturers and start-ups have explored various approaches towards implementing such communication channels, from projections on the road to LED displays behind the windscreen. However, those commercial approaches have mostly been demonstrated in the form of concept cars, through promotional materials and in the form of patents [6, 17, 19]. At the same time, the majority of HCI research on driverless cars to date has been considered from an ergonomic perspective by focusing on the user experience inside the vehicle, with few studies investigating the design of communication channels with people around the vehicle. Some examples of this are an LED strip that sits along the top of a car windshield to convey the status of the car to pedestrians [8], a screen on the front of the vehicle to communicate simple messages [2], auditory signals, haptic feedback and physical devices on a car [9].

These studies involved observing participants interacting with a vehicle that was either autonomous or pretended to be autonomous, followed by a retrospective interview. To control possible risks that are involved with studying interactions between autonomously moving cars and participants, studies have adopted approaches such as hiding the human driver behind a suit resembling the appearance of a car seat [13], using a fake wheel in a car while the real wheel was concealed [8], and using surrogate vehicles that are less dangerous such as a Segway [9]. Compared to using real vehicles, virtual reality (VR) offers benefits such as removing risks of physical injury and being able to simulate different weather conditions [11]. VR further allows for rapid prototyping and evaluation of design solutions that would be complex and difficult to build, such as placing eyes onto the headlights of the vehicle to look at the pedestrians [1].

In this paper, we draw on previous work in this area along with established HCI literature and the findings from a design study to

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Figure 1: A, B and C: Mockups showing design proposals used in the projection testing. D: The set-up for projection testing. Life-size images with design overlays were presented to participants.

propose a framework to guide the design of interactions between driverless cars and pedestrians. Even though fully autonomous cars that can operate on all roads and in all conditions are likely still a considerable time away, it is critical to already consider how these vehicles would need to be designed to cater for all road users.

The contribution of this paper is twofold. Firstly, it contributes a methodological approach for evaluating designs for driverless cars and reflections on our design study. To that end, the paper focuses on a discussion of the methods used in the design study rather than the specific design solutions. Secondly, we describe the framework we used to develop the final set of design proposals in our design study. Future studies can use the framework to guide the design of interactions between driverless cars and pedestrians, emphasising the needs and expectations of users and requirements emerging from the specific use-case scenario.

2 THE DESIGN STUDY

In this section, we describe our design process and the three stages of user evaluation, which informed the development of the framework. The design study uses Frayling's definitions of design research [5] and draws on Zimmerman, Forlizzi and Evenson's model for research through design [22], which introduces four criteria of process, invention, relevance, and extensibility as a basis to inform the research. Building on the fourth criteria of extensibility, this research develops a framework for considering how best to design interactions between driverless cars and pedestrians. This research, therefore, uses the design study of evaluating the interactions between a driverless car and pedestrians in a ride-sharing scenario as a foundation for developing the framework.

The design study involved three rounds of user evaluation: storyboard testing, projection testing, and testing in VR. This approach allowed us to remove the complexities of testing interactions between pedestrians and driverless cars, and to quickly test a large number of design proposals. Each evaluation round was tested with new participants and the findings from that round informed the subsequent round using an iterative design approach.

2.1 Storyboard Testing

Through the development and informal testing of storyboards depicting different scenarios, we were able to validate assumptions of user needs based on background research on driverless cars and current ride-sharing solutions. Three storyboards were tested with six participants (4 male, 2 female, ages 22-56) who had experience using an app-based ride-hailing service. This step loosely followed the *speed dating* method proposed by Davidoff et al. [4] that involves rapidly testing design concepts with participants in the form of storyboards. Each storyboard focused on a different user need hypothesis. Using the storyboard testing method, we found that passengers need a clear way to identify their car, are open to knowing the pick-up location of the car, are inclined towards communicating with the car through their phone, and are open to the car making decisions about their safety. These general principles were taken into the next design iteration and informed the proposals tested using the projection testing setup.

2.2 Projection Testing

Projection testing was used to test the findings from the storyboard testing session in a more realistic environment by presenting participants with life-scale, projected mockups. We prepared nine mockups, each showing a typical ride-sharing scenario (i.e. a car approaching the participant) with a super-imposed design proposal, such as an LED screen behind the windshield showing the participant's name (Figure 1A), a light on top of the car to indicate approach (Figure 1B), and an LED strip around the windshield to indicate the status of the car (Figure 1C). Some of the mockups consisted of a single image while others used a series of three to four images shown in succession to depict the car's movement towards the participant. The projection testing setup permitted us to quickly test design proposals, providing a platform for validation before designs were created in VR.

The test sessions were set up in a dark room with a projector, participants stood in front of the projector looking at various images of cars (Figure 1D), which were controlled by the researcher. We recruited six participants (3 male, 3 female, ages 19-36). For each scene, participants were asked what they would do. At the end of each scene, participants were asked to rate the depicted design solution in terms of how effective the car was in communicating its intent, how effective the car was in communicating its awareness of them as the passenger and how much they trusted the signal. The quantitative rating measure was used in a subsequent interview at the end of each session. Participants were asked to reflect upon the rating they gave, which generated qualitative insights into the importance of knowing the vehicle's intent, knowing it is aware of the passenger, and the effect of the signal on the participant's sense of trust in the vehicle.

In the interviews, participants reflected on the most intuitive signal, which signal they felt the most comfortable with, how they would improve the signals, and which signal was the least effective.

Stages of the scenario	Information		Interactions		Addressing user needs: How does the design help the user to ...			
	Location of the design	Implementation of the design	Input given to the system	Action required of the user	Identify the car	Know the current status of the car	Know the car's intent	Know the car is aware of them
Stage 1								
Stage 2								
etc.								

Table 1: The framework for mapping interactions between driverless cars and pedestrians.

The results from the projection testing, confirmed that knowing the car's intent, knowing the car is aware of the passenger, and trusting the vehicle are all important factors when designing interactions between driverless cars and pedestrians. Moreover, clearly being able to identify which car is intended for the passenger was found to correlate with trust. Based on the results from this round, we selected five design proposals to take into the following iteration. For example, we removed the proposal to have a light indicator on top of the car, akin to a taxi signal, as participants found this representation confusing. The feedback we received from participants further provided us with useful insights to revise the design solutions for the following round and to improve aspects such as clarity and visibility. For example, the concept showing LED lights around the windshield changing from red to green once the car was safe to enter showed positive results but lacked coherence. This idea was improved in the subsequent round to include a projected signal onto the road accompanied by clear textual instructions.

2.3 Testing in Virtual Reality

For the final round, we prepared five design proposals (scenes) in the form of photomontage mockups using 360-degree images, which were implemented in Unity and experienced through a HTC Vive VR head mounted display (HMD). Using VR representations provided a more immersive and realistic environment compared to the projection testing setup while minimising the risk of testing with a real vehicle. Each scene consisted of nine images to depict the vehicle approaching the participant and the design concepts were created as a way to test the importance of specific design variables addressing specific user needs identified in an early iteration of the framework, e.g. the current status of the car (Figure 2A) or its intent (Figure 2B), rather than a holistic design solution.

The five scenes were presented to eight participants (1 male, 7 female, ages 19-50). Participants were able to scroll through the sequence of images for each scene using the hand trigger control. Unlike the projection testing, this gave participants autonomy over the situation and allowed them to take the time they needed to process the information represented in each design proposal. Participants were told that the car in all scenes was driverless and we ensured that no driver was visible in any of the images.

We further used the early iteration of the framework to guide the testing script, which allowed us to assess the framework as a tool for designing and evaluating design proposals. During the tests, participants were shown each scene twice and asked by the test facilitator how well the concept addressed the user needs identified in the framework. After completing all of the scenes, a short interview was conducted without wearing the HMD.

Figure 2: Two concepts tested in virtual reality: (A) Current status of the car - waiting for passengers; and (B) The car's intent - indicating where it will stop.

2.4 Summary of Testing

The three testing rounds provided qualitative insights into the importance of various design elements when designing interactions between driverless cars and pedestrians. The storyboarding testing focused on validating assumptions of user needs that were formed from background and user research. The projection testing round focused on isolating design variables that addressed user needs and tested their importance. The VR testing allowed us to test design concepts against the developed framework as a way to evaluate both the concepts and the framework. In the VR testing round, the importance of the vehicle's current status was prioritised as this had not been evaluated in previous rounds. We found that the more effective design concepts were those that assisted the user in: (1) clearly identifying their vehicle, (2) knowing the car's current status, (3) knowing the car's intent, and (4) knowing the car was aware of them. Next we will present the emerging framework.

3 THE FRAMEWORK

Building on the findings from the projection testing, an initial framework was developed as a way to assess the design elements that facilitate the interactions between driverless cars and pedestrians in a specific ride-sharing scenario. The framework was then evaluated in the VR testing round, leading to the final framework (Table 1).

The vertical axis of the framework is structured to break down a design solution according to how information is presented at different stages of a scenario. We found in the projection testing that different design elements and indications are important to the user at different stages of the interaction. For example, in a ride-sharing scenario this might be: car is approaching the user (not yet in view) (stage 1), car has come into view (approximately 100m away) (stage 2), car is approaching the passenger (25m away) (stage

3), car pulls over in front of passenger (1-5m away) (stage 4), and car is in front of user ready to be entered (stage 5). Addressing the scenario in stages was informed by Robertson and Loke's work on designing situations, breaking down a scenario into a framework to map user and machine actions [12]. The breakdown for the stages of the specific ride-sharing scenario was informed by the broader field of proxemics and specifically consideration of social and political dimensions when reflecting on the design of interactive urban applications, such as the differences between design occupying public, social, personal, and intimate space [18].

The horizontal axis of the framework includes aspects relating to the information being displayed, the interactions between the driverless car and the user, and how the user needs are addressed. The *information* column draws on previous work about external displays on cars [3], which led us to breaking down the column into the *location of the design* (display area) and the *implementation of the design.* The *interactions* column is based on Suchman's analytic framework for human-machine communication and accordingly broken down into two sub-columns to reflect the "the user's actions" and "the machine's behaviour" [16]. Although the design solutions used in the projection testing did not extensively explore input given to the car and actions required of the user, this is still a relevant area to explore because it may pertain to more complex scenarios, e.g. if the car cannot find an appropriate place to pull over. This section of the framework was also influenced by the concept of "feedback and feedforward" [20], suggesting that interactions inherently involve feedforward, which is described as information that communicates what kind of action is possible.

The *addressing user needs* column is included to assess how the design solution addresses user needs at the different stages of the scenario. The user needs are depicted in the shaded half of the table as they are dependent on the specific scenario (e.g. ride sharing). In our study, we developed these needs through initial background and user research, which included an online questionnaire.

The framework is intended to be used as a template to design and evaluate the interactions between driverless cars and pedestrians across a wide range of use cases, as demonstrated in this paper. To apply the framework to a different scenario, the *stages of the scenario* and the *addressing user needs* section (the shaded part of the table) need to be identified by the designer. The *information* and *interactions* columns remain unchanged regardless of the scenario.

4 DISCUSSION

In this design study, we focused on evaluating specific design variables addressing specific user needs identified in our framework rather than designing and evaluating a holistic solution.

Using a range of stages (as identified in the framework), which were represented through a sequence of images, revealed that solutions in which proxemics affected the way information was displayed were preferred by participants. In other words, different design concepts are more useful to the passenger at different stages in the scenario (as depicted through the framework). For example, certain information was deemed to be useful when the car was in close proximity to a passenger but less useful when the car was further away. This finding informed the breakdown of the framework into divisive stages.

The design concepts tested in this study involved the simple scenario of a car pulling over to collect a passenger. However, the framework was developed as a tool to facilitate the design of both simple and more complex scenarios. Specifically, the *interactions* column, invites the designer to consider actions required of the user and actions available to the car while designing these interactions. For example, if a car requires interaction from the user, such as a user collecting a parcel from a car, the car would have to provide different kinds of information at different stages of the scenario. Moreover, if the car could not complete a scenario due to environmental factors (e.g. being unsafe to pull over) both the passenger and the car would need to communicate to resolve the issue.

Notably, for the ride-sharing scenario, trust emerged as a core principle relating to all user needs. The importance of trust when designing driverless cars is an area of research that relates well to our study. Familiar concepts were found to facilitate trust. When reflecting on all the designs shown in the VR testing round, one participant mentioned, "The more unlike a signal is to a normal car, the more alien it is and the more unlikely I am to trust it". This idea links back to Schneemann and Gohl [14] investigating how autonomous cars can be designed to mirror the behaviour of human drivers. Interestingly, some participants placed a higher degree of expectation on their personal safety around driverless cars compared to cars driven by humans. Participants tended to relinquish aspects of their own autonomy with the expectation that the car would infer the best action. This finding was expressed well by one participant, "To me it seems like it [the signal] is putting all the responsibility on me as the passenger. I want the car to react as a driverless car. I want the responsibility of safety on the car".

The framework was developed as a tool for considering how to approach designing these interactions and to guide the evaluation of design concepts. Building upon previous work, the framework suggests that multiple aspects of a design concept should be considered in tandem when designing, such as proxemics, data visualisation methods, and feedback. It is intended to be used as a malleable tool for designers to extend beyond the use case explored in this paper.

5 CONCLUSION

This paper investigated how driverless cars and pedestrians will communicate in an environment where eye contact and hand signalling cannot be relied upon. It focused on communication in a ride-sharing scenario with a driverless taxi car approaching a passenger it is collecting. The design process involved three rounds of user testing: (1) storyboard testing, (2) projection testing, and (3) VR testing. Through these testing rounds, four key user needs were identified as being necessary for autonomous ride-sharing design solutions to address. These key user needs are: (1) being able to clearly identify the car, (2) knowing the current status of the car, (3) knowing the car is aware of the user, and (4) knowing the intent of the car. From the design study, a framework was developed to assist designers in evaluating how well their design solutions address user needs at various stages of the scenario. The framework is informed by existing research in the field and focuses on proxemics and movement-based design. Alongside the framework, the paper offered insights into the application of VR as a tool for prototyping complex HCI systems.

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