Participatory Design in the Classroom: Exploring the Design of an Autonomous Vehicle Human-Machine Interface with a Visually Impaired Co-Designer

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Self-driving vehicles are the latest innovation in improving personal mobility and road safety by removing arguably error-prone humans from driving-related tasks. Such advances can prove especially beneficial for people who are blind or have low vision who cannot legally operate conventional motor vehicles. Missing from the related literature, we argue, are studies that describe strategies for vehicle design for these persons. We present a case study of the participatory design of a prototype for a self-driving vehicle human-machine interface (HMI) for a graduate-level course on inclusive design and accessible technology. We reflect on the process of working alongside a co-designer, a person with a visual disability, to identify user needs, define design ideas, and produce a low-fidelity prototype for the HMI. This paper may benefit researchers interested in using a similar approach for designing accessible autonomous vehicle technology.

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INTRODUCTION

The rise of autonomous vehicles (AVs) may prove to be one of the most significant innovations in personal mobility of the past century. Advances in automated vehicle technology and advanced driver assistance systems (ADAS) specifically, may have a significant impact on road safety and a reduction in vehicle accidents (Brinkley et al., 2017; Dearen, 2018). According to the Department of Transportation (DoT), automated vehicles could help reduce road accidents caused by human error by as much as 94% (SAE International, n.d.).

In addition to reducing traffic accidents and saving lives and property, autonomous vehicles may also prove to be of significant value to persons who cannot otherwise operate conventional motor vehicles. AVs may provide the necessary mobility, for instance, to help create new employment opportunities for nearly 40 million Americans with disabilities (Claypool et al., 2017; Guiding Eyes for the Blind, 2019), for instance. Advocates for the visually impaired specifically have expressed how “transformative” this technology can be for those who are blind or have significant low vision (Winter, 2015); persons who cannot otherwise legally operate a motor vehicle.

While autonomous vehicles have the potential to break down transportation barriers for people with visual disabilities, questions have arisen regarding the consideration of disabled users’ needs in the design of the technology. Organizations like the National Federation of the Blind (NFB), for instance, have argued that manufacturers are designing this emerging technology around the driver of the present, who in all cases is sighted, as opposed to the operator of the future who may be blind or otherwise disabled (Crew, 2015; Hasley, 2017; National Federation of the Blind, 2019). Under the current paradigm, there are concerns that this approach will make what could be a life-changing technology practically inaccessible for many users with disabilities.

The present report describes our experience in a mobility and transportation-related project in a graduate-level course on accessibility. We describe our experience interacting with a visually impaired co-designer and engaging in an inclusive design process of an autonomous vehicle human-machine interface (HMI). We argue that a review of our experience may be beneficial to researchers similarly using participatory design in related contexts, developers of autonomous vehicles, and educators interested in inclusive design.

RELATED WORK

Levels of Vehicular Automation

According to the Society of Automotive Engineers (SAE), there are six levels of vehicle automation (levels 0-5). Level 0 represents no automation and requires full manual manipulation of safety-critical controls (e.g. braking, throttle, and steering). Levels 1 and 2 provide driver-assisted automation of certain functions. These would include lane-keeping and adaptive cruise control. Level 3 commences the point where the vehicle takes larger control of the driving activity. At level 3, vehicles engage in “conditional automation”, meaning the vehicle can automate certain driving functionality under specific situations. Examples of level 3 automation include Tesla’s Autopilot (Tesla, n.d.) and Cadillac’s Super Cruise (Cadillac, n.d.), systems that enable the vehicle to engage in automated highway driving but requires the driver to remain attentive of the road in the event that control needs to be returned to the driver. Level 5 or full self-driving is the most advanced level of vehicular automation. Such vehicles can perform all driving functions under all conditions though the driver may have the option of assuming manual control if desired. Presently, only vehicles with automation levels 0 through 3 are commercially available in the United States. We primarily focus the case study on Level 4 and 5 automation given that these levels of automation hold the most promise for blind and visually impaired (BVI) users who cannot legally operate a Level 0 through 3 vehicle with existing technology.

Participatory Design

Participatory design (PD) is a design methodology emphasizing the inclusion of the end-users in all aspects of the design process. This design approach is based on the inclusion of representative users in the design process (Hartson & Pyla, 2019). Prior work demonstrates how utilizing PD can be an effective when designing for visually impaired users. Ghodke et al., in a 2019 study, used PD with blind or visually impaired (BVI) co-designers to evaluate four prototypes of a 3D audio-tactile globe that provided geo-spatial information to learn about geography (Ghodke et al., 2019). In 2018, Albouys-Perrios et al. collaborated with 15 visually impaired persons and three orientation and mobility (O&M) instructors to develop a prototype of an augmented reality (AR) map for O&M training in special education courses (Albouys-Perrois et al., 2018). In the aforementioned studies, there were multiple co-designers involved in the design phase; however, our study involves the participation of one co-designer. We argue that, given the low-cost, low-impact characteristics of the project and few resources available, that the participation of the one co-designer is sufficient and does not risk the over-design of the prototype (Whittle, 2014).

CASE STUDY

The following case study details a user-centered design approach for designing an initial prototype for an autonomous vehicle HMI for the accessible interaction of visually impaired users. We engaged in several participatory design sessions, in which a member of the end-user population was invited as a co-designer. The expertise provided enabled the research team to make informed decisions on what needs should be addressed while narrowing the focus of the HMI's purpose.

Participants

We recruited the participant with the assistance of the South Carolina National Federation for the Blind (NFB). Emails were distributed by NFB staff to potential participants in geographic proximity to the university campus. This study received approval from the Clemson University IRB. The participant provided consent for every session they attended and was compensated with a $10 gift card per session. Moving forward, we will refer to the participant as the co-designer for the remainder of the paper. The design process included the active involvement of one visually impaired co- designer. Our co-designer was a 40-year-old female college student who is completely blind in her right eye and has low vision in her left eye, with some color vision.

Design Process

Design session 1. The participatory design process took place across three 1-hour design sessions, placed approximately a week apart. In the first design session, the team met the co-designer, built rapport, and conducted a semi-structured interview. The interview included questions about the co-designer's day to day activities, current modes of mobility and transportation, experiences riding in cars, experiences using ride-sharing services like Uber or Lyft, and perceptions of self-driving vehicles. The interview lasted approximately 40 minutes.

Table 1. Complete list of primary user needs with corresponding sub-level needs

Primary Need	Sub-level Needs
System allows user to set vehicle's destination	• System allows user to easily specify drop-off location • System allows user to specify multiple stops • System confirms drop-off location
System ensures user's safety and readiness to begin route	• System confirms that the user is at the correct vehicle • System helps user store their belongings • System ensures user is ready for car to begin driving
System allows user to control in-vehicle systems	• System allows user to control radio System allows user to control internal temp • System allows user to control internal lighting
System's behavior is transparent	• System provides information about vehicle speed, direction, etc. • System informs user about the vehicle's surroundings • System provides information about navigation • System provides reasoning for unexpected changes in speed/direction • System alerts users to on-road hazards
System ensures user's safety when exiting the vehicle	• System informs user when the car is at the destination • System informs user when it is safe to exit the vehicle
System is usable	• System's HMI is accessible System allows user to access help from within the car

After the design session, one member of the team transcribed the interview and converted statements from the interview data into user needs. We were able to extract approximately 20 needs from the interview data.

The team grouped the needs based on their similarity into six themes or primary needs. The primary needs were that the system: 1) allows the user to set the vehicle's destination, 2) ensures the user's safety and readiness to begin route, 3) allows the user to control in-vehicle systems, 4) ensures user's safety when exiting the vehicle, 5) is usable, and 6) is transparent about its behavior and surroundings. See Table 1 for the complete list of user needs.

Design session 2. During the second design session, the team and co-designer conducted a group brainstorming session. For each of the six primary user needs, the group had five minutes to silently and individually brainstorm solutions to that need. We emphasized the quantity of generated concepts over their quality or feasibility. We wrote concepts on post-it notes. One team-member was assigned to be the scribe for the co-designer, such that the co-designer would state her ideas aloud while the team member wrote them down. After the five minutes of individual brainstorming, each member presented their ideas to the group by placing the post-it notes on the wall. Group discussion was encouraged during the presentation of ideas. Ideas were grouped based on similarity to form an affinity diagram (ASQ, n.d.). The process of generating solutions to a primary need, presenting ideas to the group, and organizing ideas took place for each of the six primary user needs. The brainstorming session lasted approximately 90 minutes. Following the co-design session, the team iterated through the affinity diagram twice by restructuring the organization of the items and generating new ideas. After these iterations, a high-level concept of the overall system emerged.

Design session 3. In the third and final design session, the team shared the high-level concept of the overall system with the co-designer. The team further exemplified the concept by sharing several written scenarios with the co-designer. The team spent the remainder of the session establishing a task flow for the final concept. The team worked with the co-designer to first create a high-level timeline of the complete experience of a single trip in an autonomous vehicle. From there, the team stepped through the timeline and asked the co-designer to complete an imaginary walk-through of how the co-designer would imagine an experience would unfold. At each step, members of the team asked follow-up questions regarding the specific interactions between a rider and an AV. Results from the walkthrough allowed the team to have a more thorough understanding of the considerations necessary to successfully design an AV human-machine interface for visually impaired users. After the third session, the team had a complete understanding of the system's task flow.

Human-AV Interaction and Wireframe

From the design sessions, we came away with insights of how someone with a visual impairment would ideally interact with an autonomous vehicle. We summarize our notes from the design sessions into three scenarios: pre-trip requirements, en-route interactions, and destination arrival.

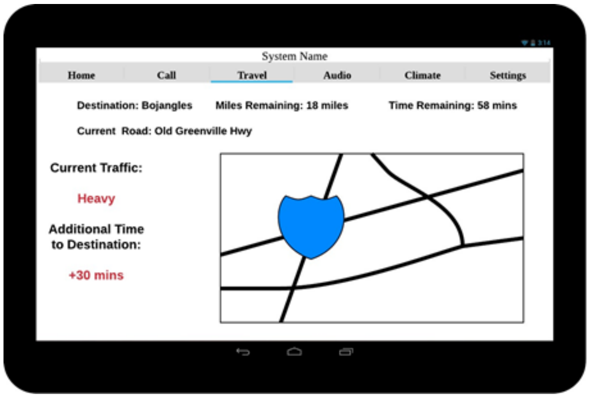
Pre-trip requirements. From the first design session, our co-designer stressed the importance for blind or visually impaired persons to have some way of customizing the experience of riding in an AV according to their specific needs. A discussion on the topic led to the idea of using a mobile application service that enables users to set up a user profile with their demographic and disability information as well as preferences based on their disability.

En-route interactions. Our co-designer explained the necessity of having multiple options of accommodations for passengers with vision impairments during the ride, especially for those who sit in the back seats of the vehicle. In terms of the AV HMI, the team agreed on the convenience of operating certain features (e.g. climate control or radio station) through either voice, touchscreen, or the mobile application. Our co-designer also made mention of enabling the AV to provide traffic and weather updates when prompted.

Destination arrival. Our co-designer introduced three important considerations: parking in proximity to the entrance, vehicle-exit navigation, and navigation to the entrance. The co-designer indicated that it would be ideal for the AV to park as close to the entrance, if not, at the curb closest to the entrance. In the event the AV had to park in a nearby lot, the AV should provide voice-based instructions on exiting the vehicle based on their orientation in the parking space. Upon exiting, the AV or mobile application should initiate navigation to the entrance for the passenger to help ensure they reach their intended location. Another feature mentioned was for the AV to alert the passenger if they leave their belongings in the vehicle.

From the insights gathered, we concluded it was necessary to develop prototypes for both an in-vehicle and a mobile application to effectively serve the needs of our users. From the design sessions, we created two task flows using the diagramming tool Lucidchart. We created a series of wireframes based on the task flows. As there was a task flow for the in-vehicle and phone interfaces, the team created separate wireframes for the HMI and the mobile application. The mobile wireframes consist of the transition between screens that the user will engage with while setting up his or her profile. The first wireframe is the login screen, while the last is a confirmation of successful profile creation and that the settings can be changed in the future if the user desires.

The HMI wireframes start with a welcome screen that is later updated with the passenger's name once their identity is confirmed. The final wireframe consists of a screen for choosing whether to dismiss the vehicle after arriving at a destination. Figure 1 shows an example of a screen that would appear while the ride is in progress. Included in the wireframes is the availability of a voice interface via the passenger speaking to the system or the system speaking to the passenger.

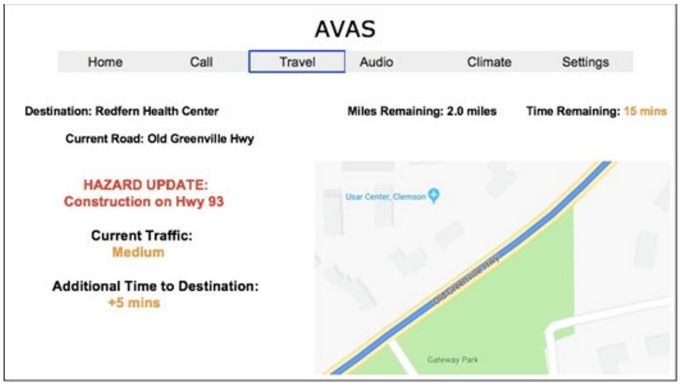


Destination: Bojangles
Miles Remaining: 18 miles
Time Remaining: 58 mins
Current Road: Old Greenville Hwy
Current Traffic: Heavy
Additional Time to Destination: +30 mins

Figure 1. **Wireframe of HMI providing traffic updates.**

Using the wireframes, we developed a prototype of a system called the Autonomous Vehicle Accessibility System (AVAS). The prototype was designed using Lucidchart. The system consists of an in-vehicle interface with a connected mobile application. While the passenger is in the vehicle, he or she will interact primarily with the system within the vehicle which consists of a touch screen interface. The first step in the interaction between the passenger and the vehicle is the confirmation that the correct person is in the vehicle. After confirming the passenger's identity, the system goes through the preparation of the ride which includes knowing the number of passengers and destination specification. In addition to preparing for the ride, the system allows adjustments based on personal preference, such as setting a radio station.

While the ride is in progress, the system can provide updates on what is occurring on the road. Figure 2 depicts an example of such an update. After the end of a ride, the system informs the passenger that he or she has reached the destination.



Destination: Redfern Health Center
Miles Remaining: 2.0 miles
Time Remaining: 15 mins
Current Road: Old Greenville Hwy
HAZARD UPDATE: Construction on Hwy 93
Current Traffic: Medium
Additional Time to Destination: +5 mins

Figure 2. **Prototype of AVAS human-machine interface indicating a road hazard**

Before the passenger exits the vehicle, the system conducts an environmental scan in order to inform the passenger of which door to exit. This functionality is beneficial for individuals with visual impairments to exit the vehicle safely without the presence of a sighted person. The system also performs scans of the vehicle's interior in order to alert the individual of any items he or she may be leaving in the vehicle.

One of the roles of the mobile application is to be used to set up preferred settings for the HMI. For example, the passenger can set the modalities he or she would like to use when interacting with AVAS. The mobile application may also be used to customize updates during travel. The passenger can control what types of updates he or she can receive, the modality through which the interface receives them, and the frequency. The mobile application can also customize climate and music control. For music control, the customization involves the device the music is to play from (i.e. radio or phone), the volume, and in the case of the radio, the station.

Another role the mobile application has is push-notifications. If the passenger were to, for example, leave groceries in the car, an alert would show on the screen in the vehicle and show on the phone with a notification signal such as a sound.

DISCUSSION

Advantages of Participatory Design

This case study has revealed the value of using participatory design techniques when designing for users who represent a population with perhaps unique needs. By including a participant with visual impairments in each stage of our design process (needs analysis, concept generation, concept selection, and prototyping), we developed a strong understanding of user tasks, constraints, context, and preferences. Input from the co-designer made design selection clearer as we were able to capture the perspective of the end-user as well as feedback on earlier iterations of our prototype.

Drawbacks of Participatory Design

While the involvement of a visually impaired co-designer proved beneficial for our design, there were some issues encountered during the process that we had to account for to make the experience work for all parties. The participatory design process required mostly visual tasks, which limited our co-designer's ability to participate fully. For example, the brainstorming session needed to be modified so that the co-designer could speak her ideas aloud instead of writing them silently, and the resulting affinity diagram was grouped visually on a wall. While the team did their best to communicate the spatial groupings of the diagram, some information was lost and the co-designer found it challenging to help the team group ideas spatially. Future work should strive to develop participatory design techniques that fully engage visually impaired co-designers.

Limitations

The limitations of our study are primarily due to a lack of time and resources. While the team much valued their access to a visually impaired co-designer, the project would have benefited from input from multiple co-designers, or additional sessions with the co-designer. For example, a session in which the team conducted naturalistic observations of the user riding in a vehicle or completing a ride-hail request would have been beneficial. Further, time constraints limited our ability to test our design iteratively. Future work will include creating a higher fidelity prototype and iteratively testing with multiple visually impaired users. Further considerations to be investigated include urban/rural contexts, young/old users, and users with multiple disabilities.

Main Takeaways

From our experience, we offer the main takeaways from conducting a participatory design session with a blind or visually impaired co-designer:

- Think about the environment you want to hold your design sessions and determine if it is accessible for your co-designer(s).
- Be prepared to adapt your user design methods to the needs of your co-designer or find alternative methods that require less or no visual proficiency.
- Prepare your design solutions in formats accessible for your co-designer.
- Carefully consider the number of co-designers necessary for your project. Consider factors such as resources, impact of product, and time constraints.

In a future study, we will conduct an evaluation of the prototype with more visually impaired co-designers to get additional feedback on its current design. Results from the evaluation will carry into the implementation of a high-fidelity prototype, for which a real-world evaluation will be conducted similar to prior work (Brinkley et al. 2019a, Brinkley et al., 2019b). This study contributes to the argument for automakers to consider the needs and preferences of people with visual disabilities in their design process and testing prototypes.

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