Universal Design of User Interfaces in Self-driving Cars

Mexhid Ferati[1], Pietro Murano[1], G. Anthony Giannoumis[1]

[1]Oslo and Akershus University College of Applied Sciences, Oslo, Norway
{mexhid.ferati, pietro.murano, gagian}@hioa.no

Abstract. Self-driving cars are already being tested in our roads, and several benefits to society are expected with their mainstream use. They also present an opportunity to increase independent mobility for people with disabilities and the elderly. To achieve this, however, the in-car interaction should be redesigned to be suitable for these groups of previously excluded car users. An investigation of existing literature helped us identify two main challenges that could impact the adoption of self-driving cars by such users, namely, their acceptance and multimodal in-car interaction. To mitigate such challenges, we propose in this paper a model that frames the process of universally designing the in-car interactions to increase usability for everyone, while maintaining safety. We argue that integrating universal design early in the development of in-car interaction will ensure their accessibility and usability by all people.

Keywords: Universal Design · Self-driving Cars · Multimodal Interaction · People with Disability · Elderly

1 Introduction and Background

The Institute of Electrical and Electronics Engineers (IEEE) predicts that by the year 2040, highways will have a special lane for self-driving vehicles [1], although many suggest that autonomous vehicles, including passenger cars, will be commonplace by 2025-2030 [2, 3]. Some scholars anticipate changes in vehicle ownership, as people will not own cars, but will pay to use the vehicle [4]. The use of self-driving cars could also significantly reduce traffic accidents and congestion [5], by enhanced inter-car communication utilizing an ‘Internet of Cars’ or ‘vehicular cloud’ [6].

According to [7] there are five levels of car automation. Level zero is when a car has no automation. Level one is when a car has some automation - e.g., adaptive cruise control or automatic lane assistant. These features are already found in many cars today. Level two provides a higher level of automation, which intends to relieve certain demands on the drivers. However, the driver is required to remain capable of resuming control of the car without an advanced warning. This means that the driver cannot focus his attention on a secondary task. An example of automation at this level is the ability of the car to maintain longitudinal and lateral control in highways. Level three is categorized as limited self-driving automation, which means that the driver may engage in other activities and they are not required to constantly monitor the roadway. In the event that the car needs a driver’s attention, they will be notified by the car. Level four is when a driver may not even be required. The car will drive itself, which suggests that car sharing may become the norm.

A recent survey conducted by Volvo highlights the importance of user interface (UI) usability for promoting the adoption of self-driving cars [8]. A well-designed user interface may increase trust between the driver and the self-driving vehicle. Typically, dashboard UIs provide mostly visual and a few simple auditory indicators to communicate information to the driver. Traditionally, the design of dashboard UIs rested on the assumption that drivers were sighted and attentive to the road, the dashboard and driving conditions. However, with the advent of increasingly autonomous cars, disability rights advocates have argued that blind people can and should have access to and use these vehicles [9].

The broad diffusion and adoption of self-driving cars, especially those categorized within levels three and four, may also contribute to promoting a more inclusive society by enabling persons with disabilities and older persons to maintain their independence [4, 9]. For example, a semi-automatic car within level three that has a UI that is accessible to persons with disabilities can enable blind people to drive. However, current legislation, in the US for example, requires a sighted driver to also be present in the vehicle [10, 11]. The blind driver navigates the car with haptic cues letting them know when and to what degree to turn the steering wheel [12].

Use and adoption of self-driving cars by older persons is especially relevant as demographers predict that the number of people aged over 65 will increase from 17% in 2009 to 30% in 2060 [13]. According to [4], self-driving cars will be highly usable for older persons and persons with disabilities. They are also providing a chance for persons with disabilities to independently ‘drive’ cars to their desired destinations.

There are, however, challenges associated with the adoption of self-driving cars. A survey study reports that people are mostly concerned with aspects of liability, cost, and maintaining control of the vehicle [11]. This research highlights the role of trust between the vehicle and the driver [7]. Research suggests that the design of self-driving cars should take into consideration the barriers that older persons experience operating vehicles, such as maintaining attention effectively [14] and the ability to effectively plan, organize, reason, and self-regulate [15, 16]. However, research has yet to explore fully the accessibility and universal design of car UIs for older persons and persons with disabilities.

This paper takes the position that the car UI should be universally designed to be accessible for a broad range of drivers. This paper initially explores the state-of-the-art of self-driving car UI design and then proposes a model for promoting an accessible UI for people with disabilities and the elderly, which aims to create a more inclusive driving experience.

2 Challenges

Research shows that the successful adoption of self-driving cars faces two challenges: the acceptance of self-driving cars, and the multimodal design of in-car interactions. This section explores the literature in these areas and proposes ways to mitigate those challenges.

2.1 Acceptance of Self-driving Cars

The acceptance of self-driving cars is a challenge for current drivers as well as potential drivers such as people with disabilities. The factors that determine adoption, however, are not the same for these communities. For current drivers, studies show that perceived control and fun decreases as automation increases [17]. With this, the attitude and trust towards self-driving cars suffers, which is more significant among inexperienced drivers and women [17]. According to another study [18], higher acceptance of self-driving cars is seen in people who are young, men, urban citizens, and those who already drive cars with some type of automation, such as advanced driver assistance systems (level one and two). The study suggests that the acceptance of self-driving cars will increase if the introduction of automatic and advanced features occurs incrementally [19].

For people with disabilities, acceptance will depend on the design of the in-car displays and the accessibility of the UIs [20]. Considering that currently 85% to 95% of sensory cues while driving are visual [21], this should not be the case with the type of interaction inside the car. One factor is that the older persons and persons with disabilities, who will become drivers, will have deterioration in visual and auditory functions [22]. Thus, if the inner design of self-driving cars does not take this limitation into consideration, such communities will not be able to use these cars. They will not be able to interact effectively with the car, which may impact trust and safety.

One of the ways that self-driving cars could become more accepted is if self-driving technologies are incorporated into all cars. However, acceptance of these technologies could be fostered by allowing owners to gradually try and test for themselves self-driving features. Once drivers would see that these features work well, are safe, usable, and have benefits, then they may be more willing to use all self-driving features.

Another aspect that often helps a product to gain acceptance and mainstream use is by showing very clearly the benefits of that product and showing how it can make life easier for users. One way of achieving this is by ensuring universal design across the whole driving experience.

On a different perspective, many technologies and products are eventually accepted because they are advertised as being something that one needs in life and eventually they are accepted by consumers. As an example, a study involving 1.6 million customers and a retailer's display-advertising on Yahoo, suggested that 'advertising profitably increases purchases by 5%' [23]. Considering this, advertising self-driving cars should not only be limited to current drivers, but should also target potential 'drivers' who were previously excluded from the market due to disability or age. However, in order to promote inclusion and target those new drivers, a universal design approach should be adopted for the in-car UIs.

Therefore, self-driving cars, once tested and evaluated as safe and useful, could be promoted in various ways through advertising and other marketing, such as through product placements in films and television programs. This would be a gradual process but eventually acceptance and normalization would likely prevail. Further, some products are given on a more long-term loan basis to well-known individuals who will then provide some opinions on that particular product (see [24] for an example).

2.2 Multimodal In-car Interaction

There are two main reasons to adopting a multimodal approach to designing the in-car UIs. First, the mainly visual interaction used in existing vehicles will no longer be sufficient to communicate alerts from the car to the driver, because users' attention may be directed at something else, such as reading a book or using a smartphone. Second, with the potential for older persons and persons with disabilities to become drivers, they may have a sensory impairment, for instance they may be blind or partially sighted or deaf or hard of hearing. Hence, the UIs should use multimodal outputs to ensure communication with the driver.

Several studies report on the importance of using multimodal outputs to communicate information to the driver [25, 26, 27]. A study by [26] investigated unimodal versus multimodal in-car interaction for alerts. They found that using only tactile or visual cues, and even when both these modalities were used in combination, performed less effectively compared to using only auditory messages. In their experiments evaluating the handover process between the car and the driver, they observed that users took, on average, 6.9 seconds to become aware of the visual alert. This number is considered high and the author suggests that other modalities should be used, or in cases when the driver is using a smartphone or tablet, the alert should be displayed on it. In essence, the study shows that alert messages should be provided via multimodal cues in order to communicate urgency effectively. In terms of annoyance, however, providing a message only using an audio or visual cue was shown to be more appropriate as multimodal cues were shown to be more annoying.

For voice communication, according to [25], a female voice was preferred, in both, English and non-English speaking countries. This suggests that for effective communication, a combination of audio, visual and tactile outputs should be used to alert the driver to resume control of the car. Similarly, [28] shows that in scenarios where drivers were required to change lanes, they reacted more quickly when the message was delivered via a haptic seat.

In terms of effort, [29] reports that visual modality compared to auditory icons or speech, was more demanding on the driver but was perceived as less annoying. The author did not find any difference between auditory icons and speech conditions. Speech was also shown to be a better modality, which resonated with the user's memory longer. Along these lines, another study [30] investigated the efficacy or different types of messages. The author differentiated between "why" (e.g., obstacle ahead) and "how" (e.g., the car is breaking) messages. Users preferred the "why", which resulted in better driving performance compared to systems that only provided the "how". Providing both though resulted in the best driving performance, but users showed increased annoyance.

Therefore, research presented in this section suggests that the use or non-use of multimodal cues is a highly complex phenomenon, because of the need to ensure safety and prevent annoyance. Moreover, the design of UIs must not overload drivers with too much information via several senses to the point that the information becomes confusing or even ignored.

3 Proposing a Model for Universal In-car Interaction Design

In the previous section we highlighted relevant factors that could contribute to mitigating the barriers to adoption of self-driving cars. To this end, in this section this article poses a model depicted in Figure 1 that frames the process of universally designing the in-car interactions of self-driving cars to increase usability for everyone, while maintaining safety.

The model is enclosed in an oval, suggesting that all features of in-car interaction should be universally designed and usable. The arrows on the oval show that the process is cyclical in nature. The solid line of the oval indicates that the principles of universal design and usability should never be compromised.

The model acknowledges that in terms of safety, in-car features could be critical or non-critical. For safety-critical features, the modality used to communicate information between the driver and the car interface will be decided by the system - i.e., the manufacturer. Considering that the messages for such features are of high relevance (e.g., various dangers on the road), only modalities that have been empirically validated will be utilized, without giving the driver the ability to change them. In other words, if the system delivers a message via multiple channels, such as visual, auditory and tactile, although it could be perceived as annoying by certain drivers, they will not be able to change it. This is depicted in the model by the double bounded rectangle with solid lines, labeled 'Safety Critical Features'. The double bounding represents the lack of user access to these specific safety-critical features.

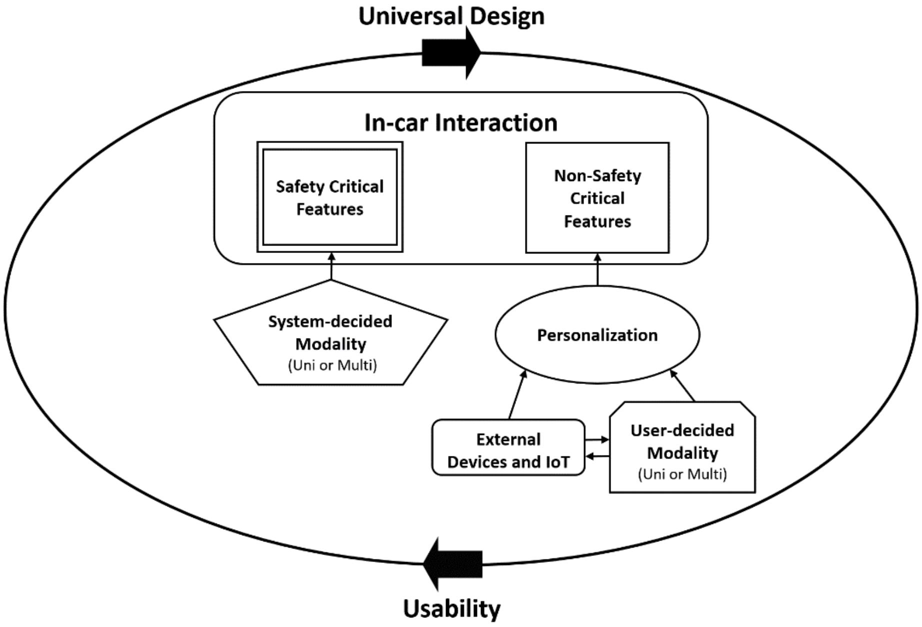

Fig. 1. A model to conduct the process of universally designing in-car interaction.

On the other hand, for non-safety critical features, although the default modality will be set by the system, the driver will have the ability to add or remove certain modalities, since such messages will not compromise safety. For example, messages that act as notices (e.g., "the car is taking a detour because of a traffic jam"), could be delivered via speech, visual or both modalities. The message is informative and if the driver does not notice it immediately, it will not compromise safety. The interface needs to provide drivers with effective methods to personalize interactions, so that an individual can more optimally allocate attention across channels - i.e., the driver may self-select how to receive critical feedback for non-safety messages.

This personalization process could be conducted by enabling the driver to change the modality via a simple interface to indicate to which channel they would like certain messages to be delivered. The system will retain that setting and all messages of that sort will be delivered only using that channel. However, there are at least two cases when this solution might not be appropriate. First, as discussed in section one, the same car could be used by many drivers. Second, there might be drivers with disabilities that may not be able to change the communication modalities if those are provided only using a unimodal interface. For example, if changing the modality is only possible via the visual interface, blind and partially sighted drivers will not be able to use it. Such a situation could be resolved by ensuring that all UIs are universally designed. One way is to make the multimodality a default for all non-safety critical features. If a user wants to personalize their experience, they can do so by selecting the modality that is most convenient for them. This will, however, imply that users need to go through the personalization process every time they drive a new car.

To avoid this issue and to ensure optimal user experience regardless of the car, developers could utilize mobile devices, such as, a user's smartphone, wearables, and Internet of Things (IoT) devices. The car interface could automatically 'read' the profile of the user from such devices and conduct the personalization automatically. This will ensure a quick adaptation to users' preferences based on their profile.

In the model, this personalization process is represented by the 'User-decided Modality', which enables users to decide the level and type of personalization. They may do this via the in-car UI or the profile data contained on their devices. This is depicted in the model as "External Devices and IoT". This relation though, is bidirectional, meaning that (1) the modality for in-car communication could be set by the data on the external device, and (2) the modality could be extended and communicated via the device. For example, if the user prefers to receive visual messages on their smartphone, then the same message could be displayed in the car dashboard and/or smartphone display. Such a feature is useful to automate for certain personalization aspects, particularly when the driver does not own the vehicle.

4 Discussion and Conclusion

The literature on self-driving cars provided a useful basis to identify two main challenges that will impact their diffusion, i.e., user acceptance and the redesign of the in-car interaction. Both challenges affect current drivers, but also, potential new drivers who were not previously able to use cars.

This article takes the position that both challenges could be mitigated by taking a universal design approach to developing in-car UIs. To this end, we propose a model that could serve as an initial guide and help raise questions and investigate solutions when designing in-car interactions. This model acknowledges safety as a crucial dimension to designing in-car UIs and integrates safety considerations with broader universal design principles.

Self-driving cars (level three, not yet four) are being deployed and tested by Uber and Volvo in Pittsburgh [31] and Tesla [32]. While these tests aim to investigate the performance and safety of the vehicle on the roadways, with this article we aim to bring to attention that we also need to begin a discussion on their universal design. Integrating universal design early in the development of new technologies will ensure that self-driving cars will be usable by all people.

This article suggests that future research should continue to test and evaluate vehicle UIs. In addition, this article suggests that future research can alleviate some of the issues mentioned in previous sections and help design and develop in-car interaction methods that allow a driver to tailor the UIs to their own preference. This would include the option of having a multimodal or unimodal approach and would depend on the driver's preference. However, the driver's preferences should not lead to a reduction in safety. Where it is empirically known that a particular modality or human sense works best in a given situation that is particularly safety-critical, this should be the only option that is available to the driver.

We acknowledge that there are other challenges that the self-driving vehicle industry must address, such as, privacy and liability. We believe these considerations are complex and should be taken up in future research. Nonetheless, the scope of this paper aimed to specifically explore the factors related to the universal design of in-car interactions in self-driving cars.

When discussing multimodal interactions in cars, this article focused on the feedback provided from the car to the driver, and not the communication from the driver to the car. There would be many occasions that drivers will need to give commands to the car, such as, destination information. We leave this as a future work to investigate universal design aspects of information input, which could be vocal, tactile or both.

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