Envisioning Tangible Controllers for Augmented Reality Windshield Display

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ABSTRACT
Drivers across the world spend a significant amount of time traveling and they often perform personal and work-related activities during their commute. The introduction of automated vehicles will allow them to reclaim some of their driving time by safely engaging in various complex non-driving-related tasks. Augmented reality (AR) windshield displays (WSDs) offer promising ways to safely present non-driving-related tasks in automated vehicles when automation is engaged. Previous studies explored different modalities like voice commands, gestures, and gaze to interact with WSDs. In this pictorial, we explore haptic methods of in-car interactions with WSDs and tangible user interfaces (TUIs). We envision our tangible interfaces, differing from conventional infotainment systems by serving as a non-intrusive remote controller supplement to WSDs. We propose two prototypes: a steering wheel attachable controller and a cup-sleeve-shaped device that aims to support the driver's ability to manipulate WSDs and efficiently transition to and from driving.

Author Keywords
Windshield display, tangible interface, automated driving, head-up display.

CSS Concepts
• Human-centered computing~Human computer interaction (HCI)~Interaction techniques

INTRODUCTION
People across the world have to commute to work for long periods of time each day [8], and during that time, they often perform non-driving-related tasks such as work or personal maintenance tasks [22, 17]. Performing such tasks while driving is risky, especially considering the distractions that arise may lead to potential accidents [16]. However, car manufacturers are developing advanced driving automation systems that can take over the task of controlling the car from the driver for extended periods of time. When in automation mode, drivers can revolutionize how they use their commute time to accomplish other tasks.

Conventional automotive user interfaces (UI) are not designed to support complex non-driving-related tasks [11, 20]. Augmented Reality (AR) Windshield Display (WSD) is a promising technology for the UI of future automated vehicles. These displays project a transparent screen on top of the driver's physical environment—their windshield. Drivers are thus able to maintain their gaze on the road while safely engaging in non-driving tasks when automation is in control. Such a display will notify the driver when they need to assume control of the vehicle and will present only driving-related information when the user is in manual control of the vehicle. Previous research analyzed interactions between drivers and WSDs using different modalities like speech, gesture, and gaze-based commands [4, 18].

In this pictorial, through a series of pictures and prototypes, we envision how different tangible user interfaces (TUIs) might help drivers safely manipulate AR WSDs in automated vehicles to perform complex, multi-step non-driving related tasks. TUIs provide users with physical control over the behavior of an interface, using a graspable object such as a remote control. Tangible interactions for simple non-driving related tasks inside the car are already common and in use. For example, buttons or knobs allow drivers to find a radio station, increase the radio volume, and start or end a call. The tangibles envisioned in this pictorial differ from current infotainment systems in several ways. Drivers will use them to control interactions that require visual attention, such as practicing presentations and navigating applications like karaoke and audiobooks. Some users might prefer tangibles to voice or gesture commands as they provide a way to merge a digital interface with the physical world, as well as to interact with the interface while keeping the gaze on the road. Compared to gesture and speech-based commands, our proposed tangible devices do not require as much visual and auditory attention; our devices could also utilize haptic feedback as an additional sensory channel. Tangible interactions have great potential to minimize the driver's mental workload and safely manage the transition between driving and performing non-driving-related tasks.

We developed two TUI prototypes: a steering wheel attachable controller (see Figure 1A) and a cup-sleeve-shaped device (see Figures 1B and 1C). The design of our tangibles drew inspiration from existing car interactions and features as well as from previous research on WSD interactions and safety. For our attachable controller, we designed a thin, plastic cuff with buttons that clips to the steering wheel. The second prototype replicates a hollowed-out, plastic cup sleeve.

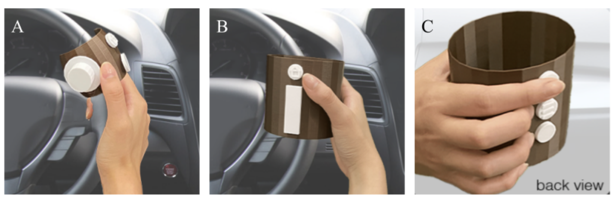

Figure 1. (A) Steering wheel attachable (B) Front of cup holder-sleeve device (C) Back of cup holder-sleeve device

Ultimately, we hope to find new ways for drivers to interact with WSDs and answer the following research questions:

RQ1: How can we design tangible controllers that can be safely used in automated vehicles?

RQ2: How can drivers effectively use controllers in the car interface to perform complex, multi-step non-driving related tasks, such as the ones presented in [4], which include: presentation, podcast, audiobook, karaoke?

RELATED WORK

Car as a Space for Work

The American Time Use Study reveals that drivers spend extended periods of time traveling to work [3]. During those commutes, drivers often perform non-driving tasks, such as answering phone calls, sending texts, and switching radio stations [22]. Yet, the danger associated with distracted driving can lead to dire consequences [16]. If people already engage in non-driving-related tasks, even in manual-controlled cars, we can expect such engagement to increase when autonomous vehicles become more readily available. Since automated driving systems are expected to hit the market within the next decade [5], it is important to look for ways drivers can safely and efficiently engage in non-driving-related tasks in automated cars.

A previous survey investigating worker responses to the idea of engaging in non-driving related tasks in automated cars found that people who already perform such tasks would be willing to continue doing so in automated cars. These drivers also anticipate being able to engage in more demanding activities [22]. Aside from this, research has shown that when people multitask and switch from one task to another, the shift in mental focus is not immediate [10, 15]. This mental effort is especially important to consider when looking at the transition from performing non-driving tasks to driving, as failure to safely and efficiently return focus to driving could result in serious implications. For this reason, our design process considered the transition from when a driver is first notified that manual control needs to be resumed to when actively performing a driving decision as a consecutive process rather than a single on-off switch [10]. Informed by this notion, our prototypes strive to simplify the steps of the process that occur when a user switches between driving and non-driving related tasks as safely and effectively as possible.

Augmented Reality Windshield Display

An AR WSD projects a transparent, digital interface over a car's windshield. Drivers are thus able to maintain their gaze on the road while safely engaging in non-driving-related tasks when cars are in automation mode. Such a display will notify the driver when they need to assume control of the vehicle and will present only driving-related information during manual control and vice versa [9]. With AR WSDs, a driver's cognitive load when switching between driving and non-driving-related tasks could potentially be lower than when other interfaces are used, as their gaze remains on the road at all times. Unlike looking at a separate screen display, a driver experiences no extreme change in gaze or focus [13]. They can interact with the interface, while also staying prepared to take control of their vehicle when necessary. However, there are still no clear findings regarding the best ways for drivers to manipulate and interact with these displays.

Much research has already been done to explore the possible ways users can control infotainment and other alike systems in vehicles. Gestures on windshield [1] and steering wheel surface [12], pointing fingers towards head-up display [7], steering wheel mounted mic and buttons for voice commands [24], and gaze [18] are some of the methods explored by researchers for interacting with WSD. Through an online elicitation study, previous research [4] examined and analyzed speech and gesture-based interaction methods on AR WSDs. Their findings suggested that the participants mostly preferred simple voice commands over gesture-based options. Many participants described voice commands to be "easier, quicker, and more precise" and gestures were "difficult." Though voice interactions were preferred because they do not require the memorization of complex and unique gestures, voice commands can also become difficult if the intended task is too complicated to explain in a few words [14]. Further, certain complex multi-step tasks, such as those demonstrated in this pictorial, raise concerns regarding the potential distractions of voice commands. For instance, if a driver needs to provide audible commands while giving a presentation to move to the next slide or start a timer, it may disrupt the flow of their task that already involves speech.

A variety of possible gesture-based interaction methods were also investigated. Several different types of in-vehicle gesture commands have already been identified: some require the entire hand to move [6], some rely solely on finger movements [7], and others utilize touch on a steering wheel [2] or on a screen surface [25]. Common concerns noted in previous studies regarding these gesture interactions are the steep learning curve, lack of motion agreement, and high potential for error [7, 6, 2, 25]. Expanding the existing research on voice and gesture-based interactions, we aim to explore how tangible user interfaces can impact and improve the way drivers manipulate AR WSDs.

Tangible Interface in Car

Most cars contain some form of tangible interactions for controlling infotainment systems, such as media and temperature control buttons, knobs, and sliders. Many cars also have additional buttons on the steering wheel to control infotainment systems, minimizing the need for drivers to take their eyes off the road and hands off the steering wheel to interact with the center control panel.

There are some commercial products currently available on the market that present opportunities to explore new ways for drivers to interact with controls for an AR WSD. For example, most cars have cup holders, and there are products that modify or make use of these storage spaces, such as cup holder expanders. These products allow users to store large bottles and provide extra storage space. Different types of steering wheel accessories are also available, such as knobs and spinners that clip to the wheel, assisting drivers with mobility or grip while turning the steering wheel.

While effective ways to interact with AR WSDs are still being explored, existing research focusing on AR in autonomous vehicles shows that tangibles have the potential to enhance and provide users with direct and physical control over the behavior of an interface [19].

DESIGNING AUTOMOTIVE TANGIBLE INTERFACE

Tangible controls that can manipulate the AR WSD in automated cars must be both functional and non-intrusive. Since conditionally automated cars require occasional user input [26], drivers should be able to efficiently and safely switch between driving and non-driving-tasks, while securing their AR WSD controllers. Hence, the placement, shape, and buttons of our prototypes were derived from interactions and movements that are already common inside cars. We aimed to eliminate potential risks, such as dropping the controller, while also prioritizing maintaining a driver's gaze on the road.

To demonstrate desired user interactions, we reused a series of referents (effects of executing an action) from a previous study [4] where users performed a series of complex non-driving-related tasks from four different scenarios. The scenarios in the study consist of personal (Audiobook and Karaoke) and work-related (Podcast and Presentation) tasks which are divided into 24 referents. The interface we envision allows users to navigate through these applications and perform certain actions. For example, in the Audiobook app, users can perform actions such as opening the application, bookmarking a section, and rewinding 30 seconds; in Karaoke, a user can select a certain category and play vocals in the background. For the Podcast application, users can skip to a specific section and text a link of the podcast to a colleague. Interactions with the Presentation app include tasks such as starting and pausing the time while rehearsing, displaying all slides, and getting feedback.

In this pictorial, we show how our 3D-printed prototypes could be used to interact with the Audiobook and Karaoke application, which are considered personal tasks (see Figures 2B and 3B), and with the Presentation and Podcast application, which are considered work-related tasks (see Figures 2A and 3A).

Tangible Interface Prototypes

Cup-sleeve-shaped Device

The cup-sleeve-shaped device we prototyped (see Figure 1A) is a hollow cylinder sleeve that can be stored inside the car cup holder area, or around a coffee cup. It mimics the shape of a standard, plastic cup sleeve and does not take away the cup space for the driver.

Figure 2. Storing and picking up the cup-sleeve-shaped device

The user will be able to slip the device out of the cupholder, without disrupting the cup, and place it back as needed, easing the transition between driving and performing non-driving tasks (see Figure 2). Reproducing the motion associated with an in-car cup holder maintains a driver's gaze on the road as drivers are already used to this motion. Some commercially available products, such as car cup holder expanders or cup holder trays, also take advantage of this space. Though they have not been tested for safety, these products are on the market and highlight how common this area already is for drivers to store cups and other personal items. In choosing to place our prototype in the cup holder area, we also avoided placing the controller near the navigation display or gear shift as drivers need to be able to resume manual driving. The positioning of the buttons on top of the cup-sleeve-shaped device are based on how drivers typically grasp a cup holder–making the buttons accessible without the need to pay visual attention to the device. No information is presented on the device itself, and there are only five buttons that need to be learned: in the front of the device, a slider, and a home button (see Figure 1B), and in the back, a select, back, and exit button (see Figure 1C).

Steering Wheel Attachable

The steering wheel attachable resembles a cuff that can be snapped onto a specific part of the wheel. Similar to the previous prototype, inspiration was drawn from current market products that have yet to be studied for safety. Products like the steering wheel knob have a curve-like bend and clip tightly to the steering wheel, helping avoid detachment. Our prototype follows that shape, but its length is shortened to take up less space on the wheel. Also, the location of this controller upon the steering wheel can be personalized to avoid interference with steering wheel grips. We expect drivers to leave the attachment clipped on; however, it can be unclipped if necessary. Since the center of the steering wheel deploys the airbags, the prototype is designed to be clipped onto the sides or upper corners of the steering wheel, minimizing potential dangers such as injuries. Differing from the cup-holder-sleeve device, this attachable only has four buttons: a spinner and a home, select, and exit button (see Figure 1A). This is a much smaller controller, thus we wanted to avoid the possibility of drivers' accidentally clicking the wrong button.

We anticipate that using either of these controllers will allow users to navigate the AR WSD interface while sitting in the driving-ready position, and expect that the transition from performing non-driving-related tasks to driving would be efficient and safe.

Prototype Demonstration

In this section, we depict the envisionment of how our prototypes could be used to safely and effectively interact with a highly visual AR WSD.

The scenarios demonstrated consist of tasks from personal (Audiobook, Karaoke) and work-related

Figure 3. Cup Holder-Sleeve Prototype Demonstration

A. Presentation Scenario

Opening the Presentation app by clicking the Select button. | Starting the timer by clicking the Select button. | Ending the timer by clicking the Select button. | Closing the Presentation app by clicking the Home button.

B. Karaoke Scenario

Selecting desired song by scrolling through the library using the Slider. | Playing the selected song by clicking the Select button. | Adding vocals in the background by clicking the Select button. | Turning off vocals in the background by clicking the Select button.

(Podcast, Presentation) scenarios. Each prototype was randomly assigned one personal and one work-related scenario, and each action was chosen to illustrate the use of each button on the controllers. The selected tasks are some of the interaction examples of the features from the applications that were used in the previous elicitation study [4].

Reading each scenario from left to right, the WSD in the image depicts the end result of the user performing said action in the caption below it. The red arrows indicate how a driver can use their hand to scroll using the slider button on the cup-sleeve-shaped device and the spinner button on the steering wheel attachable controller.

Figures 3A and 3B show the intended usage of the cup-sleeve-shaped prototype for the Presentation (work-related) and Karaoke (personal) application scenarios. For the Presentation app, a driver opens their desired presentation. Then, they time themselves by starting the timer and ending the timer when finished, and ultimately exit the entire app. In the Karaoke app, a user chooses which song from the library they want to sing. Then, they play vocals in the background and turn off after.

Figure 4. Steering Wheel Attachable Prototype Demonstration

A. Podcast Scenario

Selecting desired podcast
by scrolling through the collection
using the spinner.

Opening the share menu to show the contact list
by clicking the Select button.

Sharing the podcast link to a specific contact
by scrolling the spinner to select from the list,
then clicking the Select button to send.

Closing the share menu
by clicking the Exit button.

B. Audiobook Scenario

Opening the Audiobook app
by clicking the Select button.

Selecting desired audiobook
by first scrolling to desired book,
then clicking the Select button.

Bookmarking a chapter in the book
by scrolling to the Bookmark option
on the menu.

Adding a bookmark at the current chapter
by clicking the Select button.

Figures 4A and 4B show the intended usage of the steering wheel attachable prototype for the Podcast (work-related) and Audiobook (personal) application scenarios. In the Podcast scenario, a user chooses the podcast they want to hear, then shares its link to someone in their contact list, and finally, returns to the app's Podcast menu. For the Audiobook scenario, a driver opens the audiobook app, chooses a specific book from the library, and creates a bookmark for the chapter they are listening to.

CONCLUSION AND FUTURE WORK

In this pictorial, we envision how tangibles can be safely and efficiently used in automated vehicles to control AR WSDs. We designed two different prototypes of a tangible controller: a cup holder-sleeve-shaped device and a steering wheel attachable. Using an iterative process, we were able to create 3D-printed models with distinct buttons (see Figure 1A-1C). These models focus on maintaining a driver's gaze on the road and efficiently allow a driver to safely transition from driving to performing non-driving related tasks. The pictorial format helps to visualize the desired interactions drivers will have with the controllers to manipulate the interface and perform non-driving tasks. Here, we focused on four scenarios of non-driving related tasks: rehearsing and editing a presentation, actively listening to an audiobook, singing karaoke, and texting a podcast link to a colleague. These scenarios were discussed and evaluated in a previous study [4].

In the future, we aim to run an elicitation study with our prototypes that extends the research conducted by Ch et al. [4] to observe how drivers interact with the tangibles while driving in a simulator. We will explore task completion, error rates (of both driving and non driving related tasks), user preference, and the transition between driving and non-driving related tasks by simulating driving in a conditionally automated vehicle. As discussed in [23] we expect tangible interactions to provide effective means for users to interact with automation and AI. We focus on the domain of non-driving related tasks in automated cars, but there are dozens of other scenarios, both in the workplace and in home environments, where users could use tangible controls to safely use and collaborate with automation [21]. We believe that pictorials provide opportunities to envision and speculate on how such interactions might look like, and to evoke future empirical work.

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