Modern cars include a host of secondary in-vehicle technology that requires control by the driver. Center-stack touch-screen displays are a popular way to accommodate the proliferation of additional functions through a flexible and scalable interface. However, touch-screens require visual attention for manual selection and provide poor tactile feedback to the driver, which can pose a significant risk while the vehicle is in motion. Inspired by a bimodal control approach, we propose the use of a steering wheel mounted thumb-based gestural interface as part of a larger multi-modal interaction strategy for human vehicle interaction. Following the spirit of Guiard’s (1987) model of bimanual control, a small set of simple gestures for the right hand select appropriate functions within the mode selected by the left hand. A pilot study shows promise of this approach over other, free-form gesture-based methods of interaction.

Distractions can be classified into three different categories (NHTSA, 2011):

i) Visual (taking your eyes away from the road)
ii) Manual (taking your hands of the wheel), and
iii) Cognitive (taking your mind off what you are doing)

These types of distractions can be internal or external. Internal distractors mainly include the use of in-vehicle technologies, eating, use of cell phones, reaching for objects, and interactions with passengers.

To accommodate the large number of potential functions and controls and in response to the overwhelming success of multi-touch based smartphones, car manufacturers have turned to center-stack touch-screen information displays as the main interface element. While this undoubtedly has benefits in terms of flexibility, space savings, and visual feedback possibilities, it is doubtful that touch-screen displays are a good interaction choice for drivers while the car is in motion (Buxton, 2012). It is clear that the lack of tactile feedback and the necessity of visual guidance of goal-directed movements (categories 1 and 2 above) is incompatible with the driver’s primary driving task and temporarily leads to a significant impairment in driving performance – especially in time-critical and unexpected situations.

Given the popularity of center-stack touch-screen controls, it seems highly unlikely that car manufacturers are going to eliminate this feature from their vehicle line-ups even though they require significant visual attention to operate. In many ways, they are an optimal interface technology for the passenger, who can control many aspects of the vehicle through a conveniently located terminal, and for the driver when the vehicle is parked and the driving task does not require attention. The task for designers is thus to provide the driver with alternative control options that make the use of the center-stack touch-screen display less attractive while driving.
Many car manufacturers have already created such alternatives for their high-end vehicles. Speech-based interfaces are a convenient way to input complex commands (such as a street address for the navigation system) while driving. This technology minimizes both visual and manual load, but obvious issues of privacy and operation in noisy environments, such as during a conversation, arise. Additional buttons and directional pads integrated in the steering wheel are another approach keeping manual distraction low and the drivers’ attention and hands focused on the driving task. Buttons, however, are limited in applicability. These buttons mitigate distraction categories one and two as compared to touch-screen displays but do not offer an advanced solution to the in-vehicle control issue. A gestural interface can offer control over a broader range of functions than buttons. Incorporating this style in a multimodal interaction, i.e. speech, manual inputs, and gestures allows the driver to choose the optimal interaction style for a given situation. As Oviatt (1999, 2012) has pointed out, such a system gives the user the flexibility to select and alter between input modes, avoid errors, recover from errors, and makes it easier to accommodate a wide range of users, tasks and environments.

Gestural interfaces can be an integral part of a multimodal interface. Gestural interfaces allow users to make simple hand or finger gestures to activate different controls. Two types of gesture interfaces are free-form gestures and contact-based gestures (Hinckley & Wigram, 2012; Saffer, 2009). Free-form gestures for in-vehicle control require users to perform gestures in an area of the car equipped with the necessary sensor recognition technology to register and interpret the driver-initiated movements. Pickering, Burnham, and Richardson (2007) suggest that free-form gestures reflect a natural form of human communication and are easy to use. While free-form gestures enable drivers to keep their eyes on the road, they do not address the second category, manual distraction. In addition, free-form gestures might not be as intuitive as suggested, requiring learning of a set of arbitrary gestures before operating the car efficiently. The large number of possible secondary controls (often more than 100 and up to 700 according to Pickering et al., 2007) would require a bulky arsenal of different gestures placing a high memory load on drivers attempting to master their car’s controls directly.

Alternatively, contact-based gestures address manual distraction by allowing users to interact with the car in a different way, keeping both hands on the steering wheel and the eyes on the road. Contact pads placed on the steering wheel allow drivers to control different in-vehicle functions using their thumbs. This reduces the amount of head-down time and allows for safer driving practices. On a touchpad, users are only required to learn a limited number of easy-to-execute movements that relate to the functions the drivers wish to perform. While touchpads have not been integrated into the steering columns at this point, other manual interfaces that require operation through the thumb have been present for a long time. The steering wheel of the 2013 Ford Explorer, for example, contains many buttons: directional arrows (DPad), a selection button, and controls for the radio, phone, and cruise control. These buttons allow the driver to control different functions in the information display from the wheel without having to reach over to the center stack.

Although interfaces on the steering wheel are becoming more popular, car companies have not taken explicit advantage of the presence of two hands on the steering wheel. Models of bimanual control, like Guiard’s (1987) model, emphasize the different roles of the two hands. According to Guiard, the non-dominant (mostly left) hand sets the framework for the desired task and the right hand performs precise movements within this framework. While Guiard’s work focused mainly on bimanual tasks like writing on a sheet of paper or swinging a golf club, more abstract notions of this division of labor are apparent in other areas. In video gaming, for example, one hand often controls the navigation of an actor while the other hand controls the viewpoint or selects the actions for a given location. In our case, the application of Guiard’s model consists of the separation of mode-selection tasks for the left hand and the control of functions within that mode through gestures of the right hand (or more precisely, the right thumb). Buttons or other traditional manual controls on one side of the steering wheel could act as a mode selector while a touchpad on the other side of the wheel would allow for a limited but widely applicable set of gestures to control functions within the selected mode.

GESTURE-BASED PROTOTYPE DESIGN

Unlike the free-form gestural approach chosen by Pickering et al. (2007), we concentrated on a small number of touch-based gestures usable in different contexts. For example, many secondary controls deal with the increase or decrease of a particular quantity. All of these control functions could be mapped to the same gesture (e.g., a simulated turn of a knob or sliding the thumb up or down) once the correct mode has been chosen. A preliminary analysis of the abstract control functions required for secondary displays include the following:

- Selection of a particular item (e.g., a preset radio station or a climate control element)
- Scrolling through a list of items (e.g., different settings or songs in a playlist)
- Toggling between two different states (e.g., turning the defrost on or off)
- Increasing or decreasing a quantity (e.g., volume control or temperature control)
- Selection of a quantity (e.g., entering a particular volume or frequency)
- Approving a request (e.g., confirming a menu choice).
Gestures, unlike button presses, have a number of unique features. They can provide binary information (as a simple button press), but they can also add magnitude and frequency information through one simple gesture. The prototype used in this study consisted of a set of 19 basic and easily discriminable gestures that can be performed comfortably on a small touch pad by the thumb of the right hand while holding on to the steering wheel. These gestures consist of five simple clicking (single-touch) gestures, eight directional gestures or swipes, four continuous gestures that include two rotary gestures (clockwise and counter-clockwise) and two back-and-forth swipes, and two symbolic gestures (a check mark and an X). Using combinations of different gestures, changing the temporal characteristics of gestures (e.g., how quickly a directional swipe is executed), or using double-clicks could obviously increase the number of available gestures. However, this analysis was limited to simple gestures that are easy to learn and execute. Figure 1 lists the total set of 19 gestures used in this project.

Combining the gestures of the right hand with mode selection by the left hand leads to a rich set of potential controls. Mode selection by the left hand could be accomplished through a simple array of buttons, each representing a particular mode (e.g., telephone, climate control, cruise control, music player, radio, etc.), a DPad, scroll wheel, or by a second gestural interface. This study focuses on the use of simple thumb gestures by the right hand and assumes the correct mode is already active.

A preliminary study with 10 participants tested how consistent drivers were in creating a particular free-form gesture or selecting a thumb gesture to execute a particular control function. We used a simple set of 37 common control tasks (see below). Our main interest was to test the assumption that free-form gestures would come naturally to drivers. Secondarily, we wanted to test how consistent participants interpreted the thumb-based gestures.

As expected, the results show a wide variability in the free-form gestures participants created. Agreement scores were consistently low, with only two tasks reaching or exceeding fifty percent agreement. These tasks involved selecting numerical presets for which many participants chose a simple gesture solution and displayed the number of fingers corresponding to the desired preset number. The majority of the functions showed little general agreement, ranging from 2 to 3 participants providing the same gesture for a particular function. Several functions had no agreement whatsoever in the free-form gestures with very diverse types of gestures provided by participants. For example, gestures provided for altering the windshield wiper intensity were quite different. One participant suggested saluting towards the windshield to increase the intensity and saluting towards the rear of the vehicle for decreasing the intensity while another participant suggested rapidly opening and closing the right hand facing towards the windshield to increase the intensity and rapidly opening and closing the right hand facing towards the back of the vehicle to decrease the intensity.

Agreement in the selection of thumb-based gestures was consistently high, with half of the functions exceeding fifty percent or higher agreement. The end call function achieved the highest level of agreement, with ninety percent of participants selecting the “X” motion gesture in which the participant swipes diagonally to make an “X”. None of the touch gestures received zero agreement.

To further evaluate the potential benefits of our design we conducted a simple anthropomorphic study to determine the appropriate size and placement of the mode buttons and touchpad on a steering wheel (Figure 2). The strained and unstrained areas of reach for the thumb where measured in...
addition to the strained and unstrained thumb tap ability. A physical prototype was designed within these parameters to ensure that participants could comfortably generate gestures on the touchpad (see Figure 3).

**Figure 3.** Schematic drawing of a bimanual control prototype with button-based mode selection for the left hand (A) and contact-based gestures on a touchpad for the right hand (B).

**Pilot Study**

**Participants**

Eight University of Idaho students and community members participated in this study.

**Material**

Based on the anthropomorphic data collected in the preliminary design phase we constructed a simple, non-functional physical prototype of a steering wheel that contained a mode selection area (using nine labeled buttons) and a touch pad that was easily reachable on the right hand side of the steering wheel.

**Procedure**

The pilot study was a within-subjects exploratory design. The total duration of the study was one hour. Participants were instructed to imagine driving a car and that they had both hands on the wheel. Participants were presented a task scenario that referenced a frequent secondary control task within a vehicle (e.g., turning up the radio, switching the radio station, etc) from a total of 37 tasks spanning six task categories (radio/entertainment, climate control, windshield wiper functions, phone, window position, cruise control).

After an initial presentation of the “correct” thumb-based gesture for each of the tasks during a training phase, participants were tested on their ability to remember the appropriate gestures. The gestures were chosen based on the preliminary study described above.

We measured the number of correct executions of the combination of correct mode selection and gesture. Participants also completed subjective ratings of the interface concerning the ease of use, ease of remembering the gestures, and overall impression of a system using touch based interfaces.

**Results**

Overall, participants were capable of remembering the set of predefined gestures and physically completing those gestures with high accuracy after limited training (see figure 4.) Furthermore, participants reported high levels of satisfaction and usability as evidenced by overall highly positive responses on our subjective rating scales.

![Figure 4](image)

**Discussion**

This study demonstrates the potential of a touch-based gesture system embedded within a steering wheel. Unlike simple button interfaces or screen-based menu selection, steering wheel gestures have the ability to directly indicate amplitude, directionality, and frequency (e.g., the back-and-forth swiping frequency to the windshield wiper speed). Secondly, the gestural component in our design takes advantage of pre-existing conventions and mappings from devices found in the market today to indicate particular actions. In contrast to direct manipulation of buttons, the rich set of gestures allow for redundant mappings of gestures to actions for example, increasing magnitude or amplitude of a setting by swiping up or swiping in a clockwise motion on the right track-pad all while using natural gesture-based mode interactions on the left. Preliminary data shows that users consistently chose similar gestures or classes of gestures when asked to
perform related tasks on the track-pad. When asked to increase a setting (temperature, volume, wiper speed), users generally chose to swipe upwards on the track-pad, and they chose to swipe downwards to decrease the same setting.

The results also demonstrated the steering wheel gesture system is comfortable and easy to use. Track pad placement which took anthropometric data into account reduced strain and led to manageable swipes on the interface. By utilizing an interface based on the natural communication of gestures, participants also performed with great accuracy. The positive subjective rating results show that users are ready to accept touch-based interfaces when completing secondary tasks while driving.

Future research is necessary to address several optimization issues to make a gestural steering wheel interface more effective. Audio feedback accompanying mode changes could alert the user to the fact that they are utilizing gestures within an incorrect mode. In addition, visual feedback through the main dashboard display can also assist in providing feedback about the mode and the state of particular settings. Another issue to explore is the use of speech in addition to our steering wheel gesture-based interface. While a number of commands are easily expressed through simple gestures, other tasks—such as choosing a contact from a phone list or entering a target address for the navigation system—are tasks which may be more easily accomplished through multimodal interactions. Future research will help us understand the best task allocation between speech and gestures. Based on the success of the current prototyping studies, we hope to test the reliability and robustness of the system using the Idaho Driving Simulator, a high-fidelity driving simulator at the University of Idaho. Driver lane deviation, coupled with eye-tracking, will allow for quantitative comparisons, such as head-down time, between current systems and our touch-based steering wheel system.

More research is necessary, but if future investigations are as promising as the current study, a gesture-based steering wheel system may reduce driver distraction within the vehicle and allow drivers to focus on the primary task of driving and improve safety.

References

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