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Comparing Electrostatic and Vibrotactile Feedback for In-Car Touchscreen Interaction Using common User Interface Controls

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ABSTRACT

The automotive evolution in virtual controls for touchscreen interaction provides the opportunity to manage and manipulate In-vehicle Infotainment (IVI) system without the need for large physical control. However, as most of these virtual controls are designed for visual feedback in PCs and mobile devices, their implementation can have usability and accessibility constraints in a moving vehicle. In fact, for some controls the interaction primitives may be substantially different from the physical versions (i.e., multi-finger knobs, single finger dials etc.), therefore requiring drivers to remaster the mechanics of virtual interaction to properly utilize these controls on a touchscreen surface. Although, some IVI systems now include basic vibrotactile feedback which may only provide abstract confirmation of triggers or events, but this technique may not be ideal for calibrated tactile or textural output in a moving vehicle. Recently, electrostatic or electrovibration feedback has been proposed for touchscreen interaction which can augment the systems with clear and precise textures rendered on the touchscreen. As this technology is relatively new and may have certain limitations, it is important to understand how the usability of current graphical user interfaces (GUIs) controls augmented with electrostatic feedback may improve touchscreen interaction. This research study looks at 8 common GUI controls adapted for touchscreen surfaces primarily for visual interaction and augments them with vibrotactile and electrostatic feedback. The goal of the study is to understand which type of controls are suitable for visual only interaction, and which controls require basic tactile feedback (vibration confirmation), while identifying the GUI controls that may be most effectively utilized in the presence of electrostatic tactile feedback on the touchscreen using friction variation.

Keywords: Graphical User Interfaces (GUIs), Haptic feedback, Vibrotactile interaction, Electrostatic feedback, Human systems integration

INTRODUCTION

Human skin has 12 diverse types of afferent fibres that help perceive pain, kinesthetic, tactile, and thermal sensations (Ayyildiz et al., 2018; Sirin et al., 2019). The simple act of reaching out and touching an object engages this layered mechanism within the skin thereby helping us assimilate various properties of an object, such as form, texture, motion, pressure, and temperature (Vardar et al., 2021; Sato et al., 2012; Wijekoon et al., 2012). In Human Computer Interaction (HCI), the ability to artificially stimulate the various mechanoreceptors within the skin and simulate specific properties of virtual objects has been a key driving force in several interaction systems (Basdogan et al., 2020; Shultz et al., 2018). In most cases, these systems utilize direct or indirect stimulation of the receptors through vibrotactile input, however, such feedback can have limited perceptual outputs, especially for touchscreen interaction within vibrationally noisy environments (Farooq et al., 2017) (i.e., moving vehicle). Although vibrotactile based in modern touchscreen devices provides an easy and efficient way to relay rudimentary information, such as confirmation of discreate events, or identification of pre-encoded triggers, the inability of various mechanoreceptors to sample and differentiate vibration parameters (i.e., frequency, wave form, amplitude duration etc.) can greatly reduce the overall perceptual output of the system (Zhang and Harrison 2015). For this reason, it is important to research other techniques of stimulating receptors within the skin, such as electrostatic feedback to modulate friction on a touchscreen.

CREATING ELECTROVIBRATION FEEDBACK ON RIGID INTERACTIVE SURFACES

Modulating friction as tactile feedback on various surfaces is not a new concept (Sirin et al., 2015). Several systems and customized devices have been developed to create electrostatic forces or electrovibration with varied success i.e., Tesla Touch (Bau et al., 2010), Senseg (Wijekoon et al., 2012), STIMTAC (Amberg et al., 2011) and LATPaD (Marchuk et al., 2010). As illustrated by Bau et al., (2010) electrovibration is created using electrostatic friction between a surface and the user's skin. By conducting an electrical charge between the finger and surface of interaction, it is possible to create a temporary attractive force when the user's skin meets it. Modulating such forces on the surface of interaction it possible to generate a variety of sensations perceived similar to granular textures (Higashiyama and Rollman, 1991). The rendered textual properties may be perceived differently from those provided through conventional vibrotactile feedback and may in fact be supplementary form of stimulation. Therefore, electrovibration feedback may have the possibility to enhance and compliment conventional vibration-based output improving textural details of virtual surfaces and control mechanisms on the interaction surface (Wang et al., 2022).

However, all such systems require the user's finger to traverse through a virtual interface (i.e., touchscreen) by continuously contacting the screen. This is necessary because friction variation is most effectively relayed through comparative motion of the finger on the surface of interaction (Yan et al., 2019). Nevertheless, common touchscreen user interface controls (i.e., buttons sliders and knobs) are designed to be used for discrete interaction, where users only contact the touchscreen to trigger or manipulate these controls. This means that although electrostatic (through DC / AC) feedback (Nakamura and Yamamoto, 2017) can provide textual and tactile output for various touchscreen controls, the UI mechanism may not ideally support users' ability to explore or traverse these controls without triggering or selecting specific events (Liu et al., 2017). Therefore, certain touchscreen UI controls may be better suited to be supplemented by electrostatic / electrovibration feedback over others.

Graphical User Interface for In-Car Interaction

According to the present trends the most popular method for information presentation inside cars is the visual display. This requires drivers to take their eyes off the road and look at the complicated user interface to be able to operate it, resulting in completely shifting the driver's attention from the primary task (i.e., driving and traffic status) to a secondary task (e.g., navigation via maps or traversing a music library). This can be extremely dangerous as Lu et al. (2017), show that focusing back onto the road may take at least 20 seconds. The use of haptics and touch-actuated or gesture-based interfaces has often been considered as an option to overcome shortcomings of both visual and auditory-based information mediation (Spakov et al., 2022; Farooq et al., 2021). However, in some cases uncalibrated vibrotactile feedback utilized for IVI systems may increase driver's cognitive load and make touchscreen interaction unsafe while driving (Noubissie and Djouani, 2022). There is a need for understanding which type of onscreen GUI controls are most suitable for visual and or haptic interaction technologies and how electrostatic feedback and corresponding friction variation may be utilized for onscreen interaction in-car use.

EXPERIMENTAL SETUP

The purpose of this research was to explore a wide range of common UI controls for touchscreen interaction by having user's carryout specific tasks requiring both discrete contact as well as continuous contact on a touchscreen surface. This would aid researchers and UI designers to map which controls are suitable to virtualize on the touchscreen and identify how electrostatic and vibrotactile haptic feedback can improve interaction for each UI controls for in-vehicle interaction over visual only interaction.

Electrostatic Feedback

To create tactile feedback through friction modulation we utilized the TanvasTouch capacitive touchscreen development kit (Schmid and Maier, 2021). The device uses a dedicated touchscreen display layered with a high voltage capacitive interaction surface to relay electrostatic output to the user. The touchscreen surface is isolated from the display electronics to ensure interference between the capacitive layer and display assembly. TanvasTouch devkit connects directly to a Windows based PC as an external display and using the Tanvas API and TanvasTouch Engine it is possible to render a variety of tactile effects on the screen. For this study we modulated various frequency outputs by adjusting the Coulomb force between the isolated electrode under the touchscreen surface and the user's finger (creating an air discharge of up

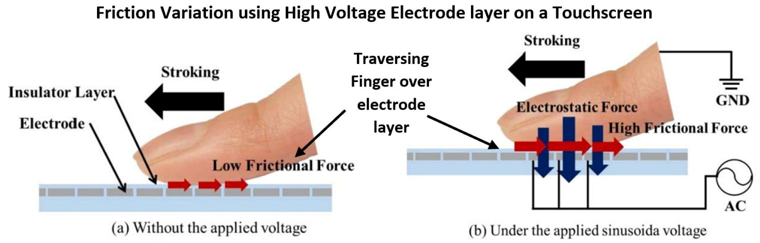

Figure 1: Illustration of how electrostatic feedback on touchscreens can create friction variation using HV electrodes.

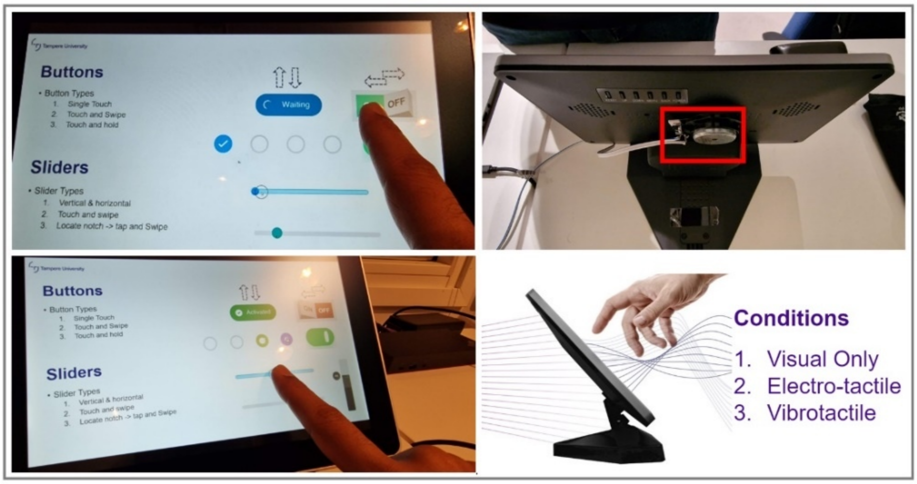

Figure 2: Graphical User Interface controls and Tanvas development device with electrostatic and vibrotactile feedback.

to +/− 8 kV, @ 25uA RMS within the UL/IEC 62368 guidelines). The resulting output simulated a tactile output of 60Hz–180Hz feedback similar to vibration stimulation.

Vibrotactile Feedback

Additionally, we also created conventional vibrotactile output on the Tanvas display using a Tectonic HIAX25C10-8/HS voice coil actuator powered by a D-class amplifier using square waves at 5Volts at 2amps. The amplitude (5V/2A) and frequency output (60Hz for confirmation and 180Hz for texture feedback) of the vibrotactile signals were calibrated through pilot testing to ensure both electrostatic and vibrotactile feedback yielded similar arousal.

Setup Design

In our study we compared 8 GUI controls including buttons, sliders, dials, knobs, gestures, lists, menus and moving an object over a tactile surface (Fig. 4), and instructed 23 participants to carry out simplified In-vehicle interaction System (IVIS) tasks in a laboratory setup using 3 conditions (visual

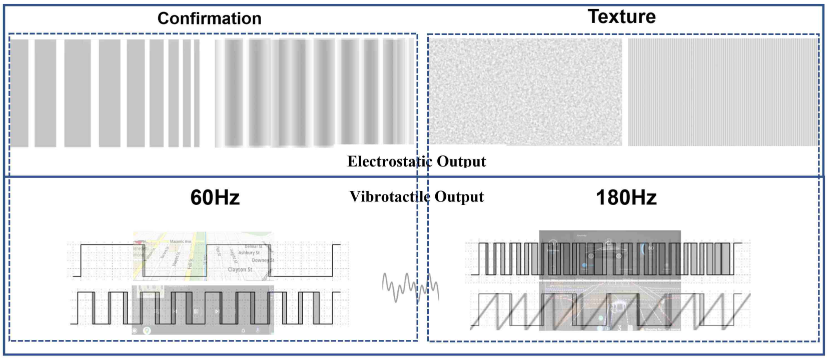

Figure 3: Illustration of actuation signals for vibrotactile feedback (bottom) and Electrostatic feedback (top) for texture output (right) and discrete confirmation (left) for each of the 8 GUI controls on the Tanvas development device.

Figure 4: Illustration of the 8 GUI controls (buttons, sliders, dials, knobs, gestures, lists, menus and moving an object over a tactile surface) and corresponding tasks associated with the 3 interaction conditions (Visual only, Vibrotactile and Electrostatic feedback).

only, electrostatic feedback, and vibrotactile feedback) where haptic output was provided as texture output and confirmation feedback (Fig. 3).

We measured task completion time, screen contact time, touch accuracy and screen pressure during the experiment and had participants fill out the NASA TLX load index questionnaire. Participants were also asked to rate the texture, selection process and overall experience of interacting with each UI control for the three conditions. And finally, a free form interview was conducted record any usability constraints experienced by the participants.

RESULTS AND DISCUSSION

Results show that for simplified touchscreen tasks, there was no statistical significance between the three feedback conditions in errors or task

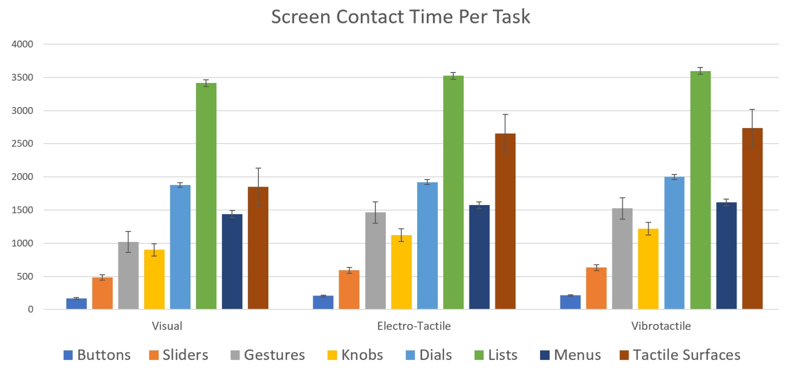

Figure 5: Screen contact time for all the 8 GUI controls across the 3 conditions visual (left), electrostatic (middle) and vibrotactile (right).

completion times, for common tasks (i.e., buttons, sliders gestures menus). However, as the tasks became more complex the participants clearly performed better (fewer errors, lower screen contact time and faster task completion times, [Fig. 7]) when electrostatic or vibrotactile feedback was provided. If we look at GUI controls, such as knobs dials lists and textured surfaces (Fig. 5), we can see that accuracy for electrostatic feedback is much higher as compared to both visual and vibrotactile feedback conditions. This could be since electrostatic feedback provides more real time actuation whilst making the appropriate selection as compared to vibrotactile feedback which only yielded meaningful output as confirmation once the task is completed. This phenomenon is far more evident for the task involving dragging a cube across a textured surface, as both accuracy and pressure exerted on the touchscreen is higher in the condition with electrostatic feedback, compared to visual and vibrotactile conditions (Fig. 5 and Fig. 6).

Measuring screen contact time (Fig. 5) for each of the task showed that GUI controls may require continuous and discrete sub-interaction. For example, traversing through a list on a touchscreen would need multiple discrete touchpoints on the screen as compared a single swipe gesture for buttons or a slider. In fact, making a selection using the "list" GUI can be considered as multiple tasks on its own. Additionally, comparing the screen contact time with task completion times (Fig. 6), we can see that the "list, dial, menu" tasks all required more attention and took longer to complete. Results show a statistically significant difference between electrostatic feedback condition and the visual feedback condition. Thus, in complex task such as these, it is useful to include real-time textural feedback to complement GUI interaction and reduce errors as well as task completion times.

Similar results were seen in the subjective evaluations. UI controls that required multiple interaction steps (i.e., lists, menus dials and tactile surface) were rated highest on the NASA TLX load index (Fig. 7) for visual only and lowest on the electrostatic haptic conditions. Participants rated these tasks as more complex and considering these GUI controls are not commonly utilized especially for in-car interaction, the results are in-line with expectations.

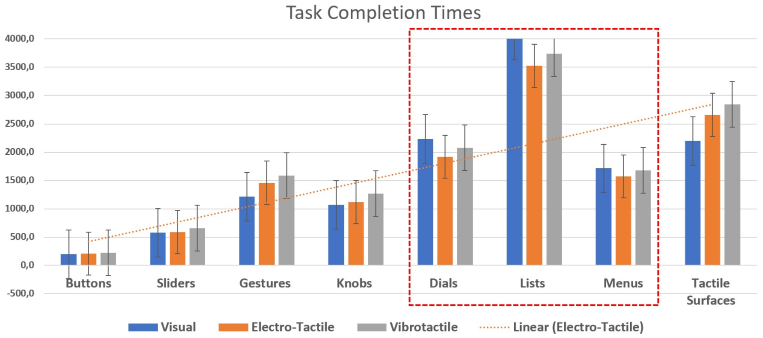

Figure 6: Task Completion Times (TCTs) for all the 8 GUI controls across the 3 conditions.

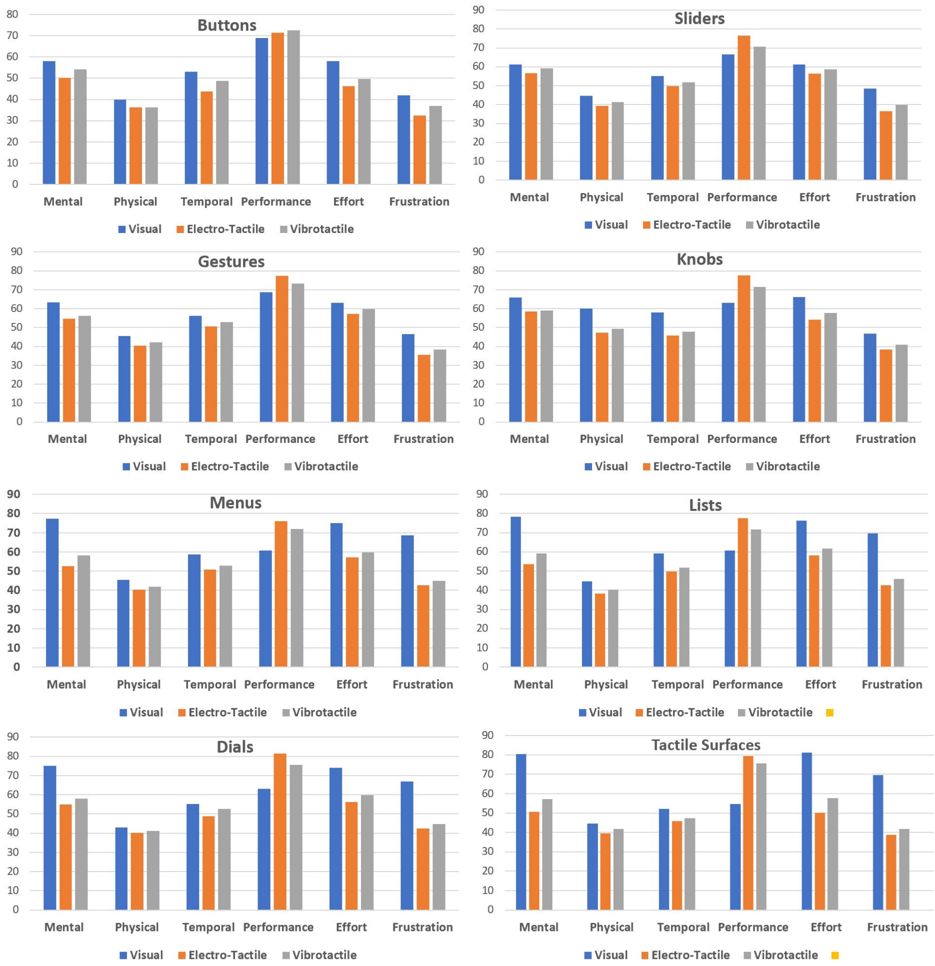

Figure 7: NASA TLX task load index results for each GUI task w.r.t the 3 conditions.

On the other hand, augmenting the interaction using electrostatic feedback shows that these tasks can be made less complex bringing down the mantal demand. However, simpler tasks such as buttons, sliders, gestures, and

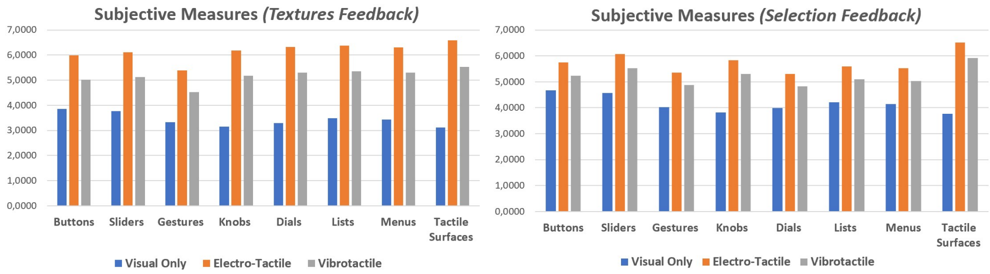

Figure 8: Subjective evaluation of all the 3 conditions for their ability to relay meaningful textural (left) and confirmational (right) feedback while performing the 8 GUI tasks.

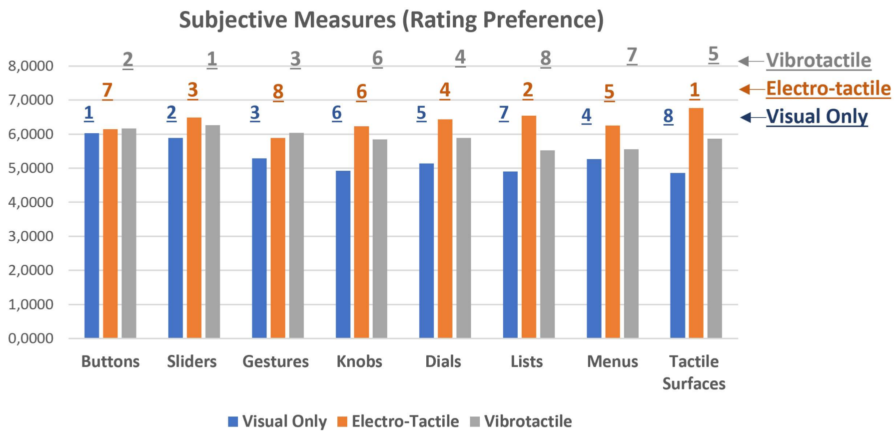

Figure 9: Participants rating of the 8 GUI controls w.r.t the three interaction conditions (visual only [**in blue**], vibrotactile [**in grey**] and electrostatic [**in orange**] feedback).

knobs can also benefit from supplementary tactile output to reduce cognitive demand, albeit, to a lesser extent as illustrated by task completion times, accuracy, and errors as well as screen input pressure.

Furthermore, when participants were asked to rate which of the two haptic technologies were more useful in relaying textural feedback (Fig. 8 left) while interacting with the 8 GUI controls, we can clearly see that electrostatic feedback was preferred. Conversely, for selection confirmation feedback, participants rated all three conditions similarly for simplified tasks, such as button selection, sliders, and gestures (Fig. 8 right). But for more complex tasks, participants preferred electrostatic haptic feedback for most of the GUI controls, followed by vibrotactile feedback. Overall, the combinations of visual and electrostatic feedback were rated as least intrusive, most pleasurable, and informative modality, especially for in-vehicle interaction systems (IVIS).

And lastly, participants were asked to rate each GUI control with reference to the three feedback conditions. This was done to understand how information should be supplemented for multimodal interaction especially in scenarios where visual or auditory modalities are otherwise engaged or cannot be utilized extensively (in-car context [Fig. 9]).

Interestingly participants rated the most used GUI controls on touchscreens (buttons, sliders, and gestures) as the top three, for visual only and vibrotactile interaction, albeit in slightly varied order (Fig. 10). This was not the case for electrostatic feedback (ESF), as participants found tasks involving tactile surfaces, onscreen lists, and sliders to be the most efficient for electrostatic output. This means that although these GUI controls are more complex and require additional cognitive demand, they can be made less intricate by augmenting them with ESF.

CONCLUSION

As touchscreen interaction becomes more widely adopted for in-car interfaces it is important to research which GUI controls may be most suitable for specific use cases. This research explores eight most utilized GUI controls and evaluates their usability (Farooq et al., 2021; Liu et al., 2017; Wang et al., 2022; Zhang et al., 2015) with reference to three conditions: visual only, vibrotactile and electrostatic output. Results show that for simplified touchscreen tasks (buttons, sliders and gestures), there was no statistical significance between the three feedback conditions w.r.t errors and task completion times. However, as the tasks became more complex (i.e., lists, menus, tactile surfaces) participants performed better (fewer errors and faster completion times) when electrostatic or vibrotactile feedback was provided as compared to visual only condition. Moreover, participants rated GUI controls which required multiple interaction steps (i.e., lists, menus) higher on the NASA TLX load index especially for visual only as compared to electrostatic haptic conditions. Overall participants preferred electrostatic haptic feedback for most of the UI controls and rated it as least intrusive, most pleasurable, and informative modality. Authors plan to utilize these results and develop customized IVIS interaction software and validate these findings in a moving vehicle where the driver's primary task is monitored.

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