Developing Intelligent Multimodal IVI Systems to Reduce Driver Distraction

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Abstract. As research into autonomous vehicles is mainstreamed, automobile manufacturers are trying to reinvent the ways we operate and interact with our vehicles. This is now more evident in the central clusters than ever before. While some manufacturers are focusing on adding touchscreens to replace most in-vehicular infotainment controls, others are trying to make the IVIS smarter and multimodal. Unfortunately, the lack of reliable tactile feedback for touchscreen based interaction in IVI systems can be a major issue. Although this may not be a critical flaw in mobile device interaction, it can be a very dangerous limitation for an in-car system where visual distraction can be fatal. For this reason, our research focuses on exploring and developing new methods of providing tactile actuation using both vibrotactile and pneumatic feedback.

Keywords: Human-systems Integration · Multimodal Interaction

1 Introduction

Currently, most manufacturers utilize custom yet rudimentary systems for driver-vehicle interaction (DVI) and information exchange. These systems (Fig. 1) utilized either an adapted mobile platform (such as Apple Carplay, Android Auto etc.) or a more traditional in-vehicle infotainment platforms (i.e. Genivi). The adapted mobile platforms such as Android Auto and Apple Carplay utilize the visual and auditory I/O mechanism from their mobile-platform core (Android, iOS) to facilitate driver / or passenger interaction. The most useful attribute of these systems is the seamless integration of Natural Language Processing (NPL). In fact, natural voice interaction through onboard smart assistants is one of the key building blocks for these platforms. However, apart from NLP, these systems provide limited usability advantages over common IVI system. In reality, as these systems create an interaction layer on top of the driver's mobile device, channeling data and services from the phone itself, which can sometime make the system more difficult to operate [1]. This is because these platforms, in most cases limit the functionalities and services already available on the mobile device, creating a workspace for the user that may be familiar yet more restricted than the user expects. Furthermore, as these systems are designed by compa-

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nies with limited experience of in-vehicle user / system interaction, their usability as well as usefulness may still need to be proven on the road. Lastly, most automobile manufacturers support these mobile platforms on top of their own custom IVI systems, which means that the driver / user must navigate through multiple systems that may have completely counter intuitive user interfaces just to carry out simple tasks.

Fig. 1. (left to right and top to bottom) Byton's Shared Experience Display, BMWs Gesture Interface, Audi A8 full touch display, GM's Cadillac User Experience 2018, Mercedes Command Online system and Tesla Model 3 IVI system.

2 Multimodal Driver-Vehicle Interaction

The most traditional way of providing information to the driver is visualization. Graphical user interfaces (GUIs) are still the most popular method of information mediation in GPS systems, radios, and mobile phone as well as other IVI systems. This is problematic, as GUIs reduce driving safety alarmingly. When a complicated GUI captures driver's gaze and attention, it demands more than 20 seconds for the driver to gain awareness of surroundings and take control over driving [1]. In urgent situations, 10 seconds is too short a time to prevent collisions or other serious accidents. HUD displays, continuous information mediation in automated driving, and glasses have been proposed to solve the problem, as they seem to be superior to manual driving assisted with dashboard-mounted displays. However, the major problem of visual distraction still remains.

Audio-based interaction reduces visual load as driver can use speech for input and get audio as a response. Meantime, in addition to traditional synthetic speech samples and warning signals (beeps), directional and spatial audio has been implemented in IVI systems as feedback methods. Several studies indicated that such specialized audio cues work better than unlocalized sounds. Furthermore, studies show [2] that abstract audio signals worked only when presented from the center of gaze and attention (in this case, tablet) instead of, for instance, behind steering wheel. However, audio might easily be neglected due to environmental noise inside vehicle, and therefore is not sufficient for information mediation.

The use of haptics and touch-actuated interfaces has often been considered as an option to overcome shortcomings of both visual and auditory information mediation. Our research in the field [3], shows that complementary haptic cues may reduce the visual workload and decrease reaction time for driving-related tasks. Haptic feedback or clicks have also shown [4] to significantly improve user satisfaction and task completion times when operating with touch screen. Even though there has been plenty of progress in haptic technologies recently [5, 6], most used haptic interaction methods still produce vibration making them prone to left unnoticed due to environmental trembling. Another significant problem of the technology is the driver's need to touch the device operated. This means that at least one hand needs to be taken off the steering wheel to be able to operate the UI, which can be seen as somewhat problematic. Therefore, IVI systems should utilize different modalities suitable for the task and particular situation. Our research [3, 4 and 6] has already started to solve this problem showing, that it is possible to provide driving information and improve driving performance by augmenting current environmental and telemetric information through haptic information channel as well as visual and auditory feedback.

3 Multimodal Interaction: System Design

To ensure an intelligent and useful interaction system can be developed for future IVI systems, we focused our efforts in two key areas. Redesigning how users interact and get feedback from the center stack (touchscreen) while reducing the amount and type of information that needs visual confirmation; and proposing novel ways on of interacting with IVIS (via the driver seat). In this section, we go through each area of focus by discussing the prototype devices developed to enhance user interaction.

3.1 Touchscreen Interaction

To improve haptic feedback in the moving car we developed an advance layer of tactile feedback that could reduce the need for continuous visual validation. This device uses a transparent overlay that generated skin micro-displacements by moving side to side on the touchscreen. This type of actuation was designed to create more reliable feedback for touchscreen interaction in a haptically noisy environment. The tangential actuation of the screen overlay consisted of three Tectonic actuators (TEAX14C02-8) attached to an L-shaped bracket and fixed to the touchscreen overlay. On actuation of the PET film (~100mkm thick), the overlay displaced the users skin, in contact with it, creating tactile actuation. The overlay covered the entire screen of the Intel ExoPC slate, used in the prototype, and sat almost flush with the screen.

The second novel device in our research utilized pneumatic feedback to avoid (vibration) signal attenuations. As this method bypasses vibrotactile actuation altogether, therefore, noisy road vibrations do not affect it. The device, Pneumatic Subwoofer (PSW), (Fig. 2) created pressurized air pulses via two hermetically sealed subwoofers in a closed chamber and funneled the air pulses onto the surface of ExoPC tablet's touchscreen. The prototype provided variable magnitude of pneumatic pulses via a modulated digital sine wave generator regulated to translate signal amplitude and frequency into pneumatic haptic signals. The PSW device used two standard (Raptor-6) car-woofers of 140Watts each with (2*4) 8 ohms load impedance and uses a maximum of (6.5A*2) 13Amp of current. The setup was tested in various environments to ensure its reliability and usability in actual moving car was not affected due to environmental noise.

3.2 Novel Methods of Interaction

Improving how drivers navigate on the road is a key component of reducing driver distraction. Our research focused on shifting this visual-attention-heavy task and introducing haptic feedback to reduce driver distraction. The Haptic Seat prototype provided three distinct types of actuation cues; simple event based cues; spatial navigation (directional); and cues / alerts for warnings. The prototype used Tectonic TEAX25C10-8/HS actuators embedded on either side of the driver's seat, to provide vertical actuation while two Fukoku USR60-E3T ultrasonic motors with asymmetrical arrangement of spherical touch points were used to generate directional actuation (Fig. 2). The motors were used to compliment the Techtonic actuators and provide the directional feedback needed to perform the navigational task. Essentially, the directional rotation of the motors along with the degree of their rotation provided the necessary (complex haptic) information needed to complete the navigational task. Using rotations of 120 and 270 in two distinct bursts, the prototype provided instruction of right and left turnings as well as hard turns or U-turns.

Fig. 2. (Left to right) LSE TS, PSW pneumatic and Haptic Seat prototype devices.

4 User Study & Results

In total, three studies were conducted in the research to evaluate the various techniques / prototypes. The first study was carried out in a Volvo XC60 being driven in a straight line by professional drivers on the Nokia Tires Track (NTT). The purpose of the study was to evaluate the effectiveness of providing pneumatic actuation on the central touchscreen for text entry and menu based selection tasks as compared to simple vibration based feedback. The second study was conducted to evaluate the tangential / lateral actuation approach on a touchscreen device and it was carried out on a patch of highway within the participants' own vehicle. The third study was conducted in a laboratory setup using the driving simulators (Lane change test software) to compare navigation feedback using conventional audio cues as well as haptic and audio cues using the Haptic Seat prototype. This section details the design of these studies as well as the testing parameters utilized in the design.

4.1 Road Studies 1 & 2

Studies 1 & 2 had identical tasks, which involved completing three usage scenarios (text entry, selecting menu option & performing a gesture). The participants (N=14, M=6, F=8) needed to complete the task as soon as possible using the relevant type of device feedback (PSW in study 1 and LSE in study). To replicate the generic vibrotactile feedback method, we developed a custom vibration based actuation system (CVAP) and used it as an experiment control in both studies. The participants completed these tasks in two scenarios, 1) while driving on a straight road at 45km/h in a no traffic area, 2) while the car was stationary in the parking-lot.

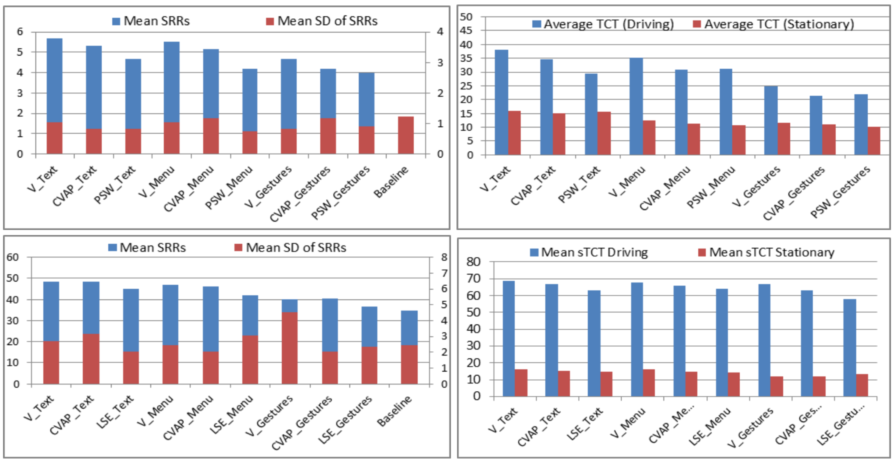

Fig. 3. Primary task (left), and secondary task performance (right) using PSW and LSE device prototypes in studies 1 & 2.

We measured the primary task performance by looking at the Steering Wheel Reversals (as suggested by SAE J2944_201506). To measure the secondary task performance we looked at task completion times and task errors. The results (Fig. 3) show that the participants performed worst in driving tasks where there was no multimodal / haptic feedback. However, amongst the three haptic feedback techniques (CVAP, PSW & LSE), both LSE and PSW improved performance of primary and secondary tasks.

4.2 Lab Study 3

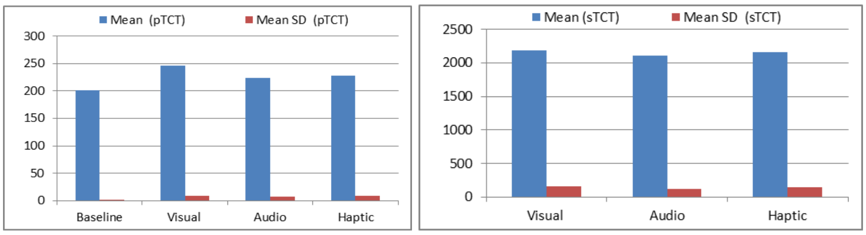

Fig. 4. Primary LCT task (left), and secondary Navigation task performance (right)

Study III was conducted in the lab where the primary task was to follow the LCT simulator and secondary task was to identify the navigational cues by pressing the correct button on the steering wheel. All the participants (N=24, M=16, F=8) utilized independent interaction modalities (Visual only, Auditory only & Haptic only) to complete the secondary task, comparing devices as well as modalities in the study. Looking at primary and secondary task performances, audio & haptics only modalities, yielded fewer errors compared to visual only modality (Fig. 4). Furthermore, it also increased the task completion time considerably. Although haptic based interaction was fast and yielded least amount of primary and secondary task errors, it was not as fast as audio only feedback. We think this may be because the participants were not very familiar with the type of haptic feedback and its use in navigational tasks.

5 Conclusion

The results of this research show that some tasks can be extremely difficult to perform within the driving environment by simply using visual interaction. These include 'text entry' as well as 'layered menu selection' on a touchscreen-based device. IVI system designers should try to limit the need of such tasks in day to day scenarios. However, as these tasks are inherent to the systems, the interaction methods need to be carefully developed to reduce driver's visual and cognitive distraction. The results of Study I and II clearly show that haptics is key for supplementing visually intensive IVI tasks. Moreover, results of Study III show that although complex haptic signals require cognitive over-heads to identify and decode the applied signals, application of more natural information signals can be as fast to decode as audio cues. Furthermore, the results point towards very limited, if any, performance-degradation of the participants in cognitively demanding primary task (LCT). Although more research is needed to identify the particular usefulness of the tested prototype, especially outside lab conditions, it is possible to relay complex haptic information to users without the need for extensive training.

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