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Improving Automobile Driver Safety and Experience when Performing a Tertiary Task using Visual, Hands- free and Gestural-based Interfaces

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ABSTRACT

Automobile manufacturers are constantly trying to keep up with current technology trends and respond to today's societal challenges. Cars have become more than just a means for transportation, they are now a fully embedded technological 'multifunctional living space'. The increased complexity of automotive user interfaces, driven by the need for using consumer electronic devices in cars as well as improving comfort, and the overall user/driver experience, has sparked a range of new research within this field of study. The number of infotainment functions (controlled as tertiary tasks) with which a user can interact while driving has greatly increased, making the primary task of driving even more challenging. In creating a better automotive user experience, automobile manufacturers have unintentionally increased the cognitive load of the driver when they are performing these tertiary tasks. This research study aims to reduce the cognitive load of the driver/user by suggesting novel, simple menu design interfaces, which add design improvements in two function aspects (entertainment and comfort) by implementing visual, hands-free and gestural based interfaces. This research study will add to the body of literature aimed at improving driver safety and driving experience while performing a tertiary task.

Keywords: **- Driver** safety, Automotive user experience, In-vehicle infotainment system, Hands-free interfaces, Interface design.

I. INTRODUCTION

To understand the context of the research presented within this paper in the field of automobile user experience, it is important to have basic insight and clarification of certain keywords and theoretical concepts concerning driver safety, driving as a task and the automotive user experience domain. An automobile's interior space can be divided to accommodate its function and the informed driving tasks [1]. The separation of these tasks within the automobile's design space provides a basis for analyzing driver tasks (specifically the tertiary task). This is particularly important when considering the design of a modern vehicle dashboard, as this task separation can be used to identify the different user interface arrangements within modern vehicles.

Three major driving tasks (primary, secondary and tertiary) have been identified [2].

A. Primary Tasks

Primary tasks involve all activities that are required to manoeuvre the vehicle. The goal is to keep the driver as visually focused as possible on the primary task (driving) while performing tertiary tasks. Any lapse in this task directly affects the overall driving experience and safety of the driver. Therefore, maintaining alertness to traffic and other potential hazards when performing this task is a priority (Figure 1).

B. Secondary Tasks

The secondary tasks typically include all other tasks that support the primary (driving) task. It includes functions that ensure driving performance and safety such as signalling, using the windshield wipers and other support tasks (Figure 1).

C. Tertiary Tasks

Any task that involves the driver's attention in order to perform, typically falls under this categorization of task. This refers to all tasks related to the infotainment system and environmental comfort of a vehicle. For example, having a conversation with a co-driver or choosing a destination on a navigation screen. While undertaking these tertiary tasks, attention moves back and forth between the centre (primary) and the periphery (tertiary) of attention [3].

This can lead to dangerous situations, if the primary driving task is in the periphery of attention for too long, a driver might cause an accident. In cars without driving assistance, the primary task must always be the focus of attention.

D. Peripheral Interaction

Peripheral interaction focuses on the interactions that can take place in the periphery of attention. These interactions can become the primary focus of attention, whenever the task becomes important to a driver [3]. It is important to understand the behavioral change when a driver switches between tasks. For example, when a driver looks away from the road to change the music on a dashboard infotainment screen (switching from primary to tertiary attention). This is particularly important when both tasks demand a significant level of visual and cognitive attentiveness. As tertiary tasks move into the center of the driver's attention more often, significant amounts of cognitive resources will be no longer claimed by the primary task.

E. Driving Tasks

For the purposes of this paper, all driving-related activities will be comprised of all tasks performed to safely control the vehicle (primary tasks). Non-driving-related activities will be comprised of all activities beyond manoeuvring the vehicle (tertiary tasks). Infotainment features of modern automobiles often enable drivers to perform multiple task while driving.

Therefore, a clear definition of the tasks within the scope of this research study sets the precedence on which interface design recommendations will be made.

In order to understand the impact of an improved driver experience, it is important to study and investigate the specific details required for each task. It should be possible to assess the impact on the cognitive load of a driver when performing a task, due to an improved infotainment interface design [4].

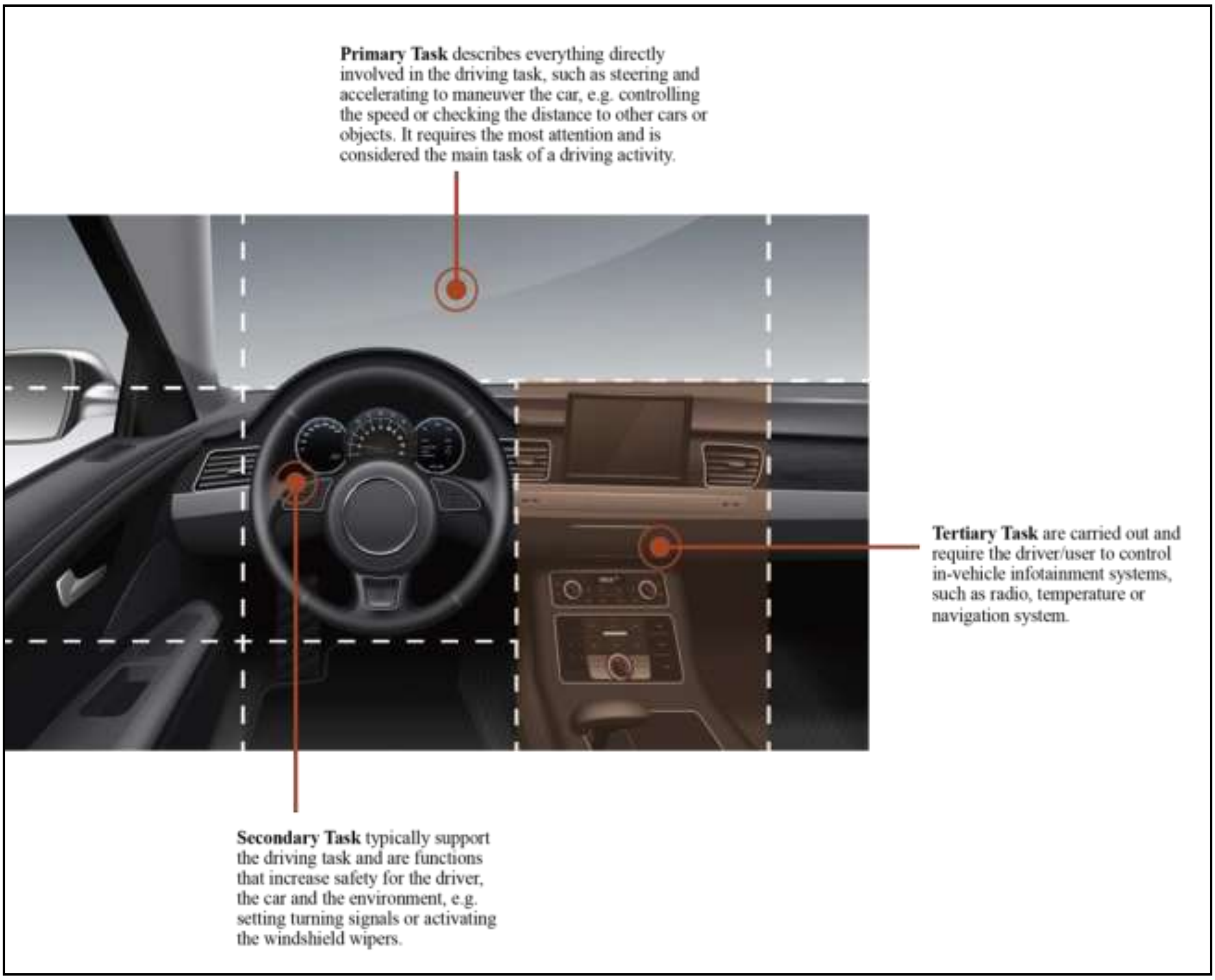

Fig. 1 Distribution of the various driving tasks [1]

II. LITERATURE REVIEW

One may argue that the current range of infotainment systems installed in modern vehicles are intuitive. Many are designed to facilitate a driver rapidly performing a tertiary task, while driving.

Several studies have also suggested that driving performance is significantly affected by aging, which may be attributed to physical and cognitive impairments [5, 6, 7]. This research has specifically shown that age has significant effect on speed variability and deep comprehension among drivers over 75

years old during non-driving-related activities. If an infotainment system poses a risk to elderly driver safety based on lack of comprehension while performing a tertiary task, it ultimately poses a safety risk [6].

Elderly drivers' cognitive limitations lead to an inability to perform tertiary tasks safely. Hence, execution of the primary task (driving) can be even more challenging to these groups of drivers, ultimately affecting their overall driving experience and safety [6].

Developing a menu interface that takes into account older people's physical and cognitive characteristics (i.e. in its design and in the features embedded) when performing a tertiary task requires adopting certain design guidelines. These guidelines aim to ensure that these tertiary task interactions are performed safely, and that they enables the rapid completion of these tertiary tasks.

A. In-Vehicle Infotainment System (IVIS) Tasks

Many drivers prefer listening to something to change their mood, feel more relaxed, or entertain themselves on both familiar and unfamiliar roads during long drives [8]. Many drivers have also stated that they listen to different radio stations for approximately 72% of the total driving duration [9]. The majority of these activities are undertaken using the interface to an In-Vehicle Infotainment System (IVIS).

For the purposes of this paper, all interaction with an IVIS interface is to be considered as a tertiary task for a driver. Device manufacturers continually strive to add more infotainment functions, without updating or expanding the range of design interfaces. This can make interaction more challenging for the driver, even when performing simple tertiary tasks. This, in turn, can negatively affect their overall driving experience and safety.

Most tertiary tasks contained within current infotainment systems require a significant cognitive load, requiring the use of both visual and working memory. Many touchscreen infotainment menu interfaces are result oriented, providing visual confirmation and feedback.

Research on the use of multiple modal user input to interact with interfaces has shown some interesting results. Infotainment menu systems that rely primarily on hands-free (voice commands) and gestural based interface modalities can be effective in improving tertiary task performance [10].

Voice enabled interaction systems are well suited for in-car applications. Driving is an eyes-busy and hands-busy task and the only wideband communication channel left is speech [11]. Research on Intelligent IVIS has shown that a major challenge is the ability for the driver to accurately sense the environment, in order to autonomously control a car without any intervention by a human [12].

B. Usability in (IVIS) Interfaces

A number of research experiments have examined the interfaces of IVISs, with the aim of benchmarking and evaluating their usability. According to the experiment "a driving simulator with two typical in-vehicle infotainment systems (a physical panel and a touch screen), and a radio tuning task was used as a test case. The results showed that the software was able to generate task performance and workload estimates that are similar to the empirical data from human participants" [9, 12, 13].

But, as seen in the results of the experiment conducted by Feng et al (2014), digital models and well-designed prototypes can be used to test design concepts and properly evaluate the usability of an interface (i.e. an IVIS menu interface) that supports the performance of tertiary tasks. Being labor, time and cost effective, the use of such high-fidelity prototypes ultimately allows the designer/researcher to explore a larger design space and address usability issues at the early stages of the system design process [13].

C. Menu Types

Research has been undertaken to investigate the type of menu design for instrument clusters in an IVIS, the results acknowledged the presence of driver distraction, its safety implications and the use of a driver's cognitive resources when operating an IVIS menu [14].

This analysis showed that the efficient navigation of an IVIS menu meant the evaluation of four different menu types including: paging, flow, icon, and list type menus.

"Task performances, menu type preferences, and eye movement patterns were measured in this experiment. The result shows that icon type was the best design in aspect of task performance and preference. A clue for the next menu item provided a positive effect for efficient menu navigation." [14]

His work demonstrated this menu type study can be effectively implemented and is in line with the research study described in this paper. The implementation and design can be explored through a basic menu utilizing the development of icon features for a prototype IVIS menu system.

D. Precision Pointing and Graphical Interaction with Specific Targets

In developing a working prototype that supports the performance of tertiary tasks and the use of both hands-free and gestural touch-based interface, it is important to maximize efficiency when acquiring or selecting a specific target feature on the infotainment menu interface.

A controlled experiment conducted in 2009 gave rise to a new technique called Dynaspot. This technique was developed for target acquisition based on the area cursor, hence it minimizes visual distraction, allows pointing anywhere in empty space without requiring an explicit mode switch, and thus enabling users to perform common interactions such as region selections seamlessly [15].

Based on Fitts' Law [16], this technique of input selection of targets on a screen has been proven to significantly outperform the point cursor and achieve pointing performance similar to the bubble cursor especially in various screen menu layout configurations. Therefore, it is a potentially ideal design detail that can be implemented in the IVIS menu layout of the prototype. In many IVIS menus, in order to maximize the efficiency of target selection, several techniques focus on increasing the target width of the icon. DynaSpot on the other hand, builds upon area cursors [15].

This makes this technique more effective because the potential equivalent width of a target can be larger than its actual width and as such making touch based selection of any icon easier.

The development of the prototype to be used in this research followed a standard design methodology, beginning with an analysis of the literature and the setting of constraints. The prototype design then moved from low-fidelity prototypes to the final high-fidelity design (Figure 2).

III. RESEARCH QUESTIONS

The principle research question for this study was :

Will improving the design of the IVIS menu interface with a visual, hands-free (voice-command) or gestural-based features improve automobile driver safety and experience when performing a tertiary task ?

However, in this study, the focus will be on two main tasks related to the driver/user performing tertiary tasks: entertainment and comfort.

- The Entertainment Tertiary Tasks (ETT) will include music selection (changing radio stations and/or music selection) and volume change (increase or decrease).
- Comfort Tertiary Tasks (CTT) will include air conditioning changes and temperature control (increase or decrease).

This research will focus on the performance of these tertiary tasks during an automated driving activity, and the entertainment and comfort features of the IVIS for the following reasons:

These two aspects of tertiary tasks (entertainment and comfort) have been demonstrated to be among the more complex tertiary tasks and require a shift in longer execution times, as well as more focus and attention compared to other tasks [3]. Hence these tertiary tasks can significantly affect the overall automotive driving and user experience.

As cars become more than just transportation tools. It is important to meet the challenge of humanizing the in-vehicle technology for a better holistic experience and inform design updates that will improve driver safety and experience when performing these tertiary tasks.

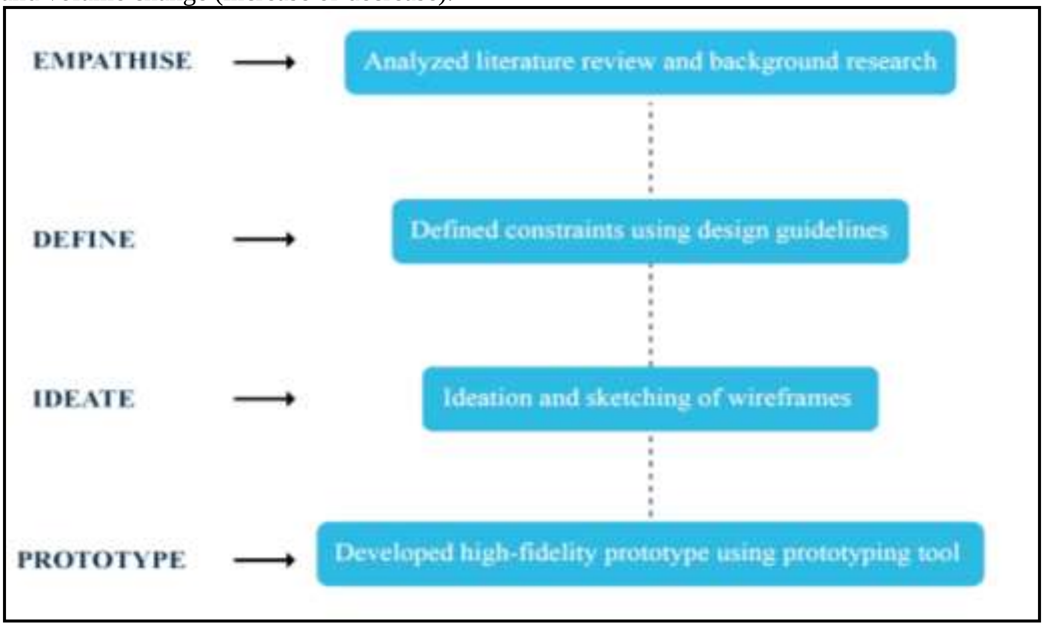

Fig. 2 Visual representation of the procedure used in this research study

IV. METHODS AND PROCEDURES

To address the research question, initial work involved the analysis of related scientific literature. This allowed a review of relevant interaction analysis and interface based of design guidelines. The constraints and limits of the study were then defined. Conceptual wireframes were also developed which focused on the two tertiary tasks (i.e. entertainment and comfort). Finally, a high-fidelity infotainment prototype was built to use in this study (Figure 2).

This methodological approach helped to offer design recommendations and suggested improvements to the wireframe of future prototype designs of an IVIS menu that supports easier execution and performance of tertiary tasks (i.e. the entertainment and comfort tasks). The approach also provided design data for the prototype model for validation purposes.

The overall design procedure essentially involved a linear design thinking process. Involving a step by step development strategy using background research/literature to developing the prototype using a prototyping tool (Adobe XD).

A. *Design and Evaluation*

In order to achieve a positive user experience in the prototype design of the IVIS, multiple practical design guidelines had to be taken into consideration. Design guidelines are sets of recommendations towards good practice in design. They are intended to provide clear instructions to designers and developers on how to adopt specific principles

It is important to have a well-defined goal and mission in achieving a well thought out design. The goal in this case, was to develop a prototype of a user interface of an IVIS that affords the user (i.e. the driver) improved tertiary task performance. Where working memory is required, but not overtaxed, and there's less dependence on very long visual demands that attribute to driver distraction [17].

Design guidelines fall into several distinct groups. However, it is very important to apply these sets of design recommendations to a specific context of use (i.e. automobile safety and user experience) and type of interaction (i.e. performing entertainment and comfort tertiary tasks).

The design guidelines for this IVIS will also take into account the specific requirements set by the National Highway Traffic Safety Administration (NHTSA). The design of this IVIS menu interface utilized a combination of these design guidelines, to mitigate distractions while further improving safety and driving experience. Also, the principles proposed and interpreted by multiple theorists in HCI were also assignable to the design of this IVIS menu system [18]. A number of the significant theorists and their key recommendations are shown in Table 1.

TABLE I
TABLE CONTAINING VARIOUS THEORISTS [18]

	Hansen	**Shneiderman**	**Norman**	**Morville**
1	Know the User	Strive for consistency	Visibility	Useful
2	Minimize memorization	Enable shortcuts	Feedback	Usable
3	Optimize operations	Informative feedback	Constraints	Desirable
4	Engineer for errors	Design to yield closure	Mapping	Findable
5		Simple error handling	Consistency	Accessible
6		Easy reversal of actions	Affordance	Credible
7		User in control		Valuable
8		Reduce memory load		

B. Design Guidelines

For this IVIS prototype, Jakob Nielsen and Rolf Molich's Ten User Interface Guidelines were used for the interface design. These design guidelines were listed in a physical worksheet proposed by Gardner-Sharp [18]. This served as a physical brief and helped identify any design related issues that informed the elements and features being integrated into the prototype. These guidelines were utilized in the implementation of various design elements (i.e. functional and aesthetic) and for the GUI features to create a functional and desirable user interface.

The guidelines are as follows [18] :

1. ***Visibility of System Status:*** The user will visibly be able to see their task operation and activity being performed on the interface. The prototype was designed to give feedback in a timely manner when a task is performed by the user. Micro-animations and subtle design changes (like the changing in color of an element) when selected, served as a form of visual feedback and communication from the system (prototype) interface to the user (driver).

2. ***Match Between System and the Real World*:** The interface included touch-screen features, such as buttons and sliders that replicated the manual and physical counterparts found in older model vehicles. Most features and components of the prototype were properly labelled and used language that the user would be familiar with. The use of real-world conventional icons in the prototype also helps users properly identify the features available in the interface. For example, the 'microphone icon' bordered lightly with fairly opaque circular rings on the interface represents the 'voice command' feature, as it would in other applications familiar to the user.

3. ***User Control and Freedom:*** The user is able to utilize the interface freely, and perform the tertiary task embedded in the interface seamlessly and intuitively using hands-free (voice commands) and touch based gestures on the prototype. The prototype interface also affords the user to return and exit a screen with the 'back button' feature at all times.

4. ***Consistency and Standards:*** The interface maintains a standard look and feel to drive consistency and standard in design. This is particularly noticeable in the utilization of familiar terms and icons for controls traditionally found in cars. For example, the color of actionable elements or features selected by the user prompts a change to a lighter blue color than when that feature is in an 'idle' state. To ensure consistency, this color change applies across all features in the prototype when they are selected.

5. ***Error Prevention:*** To prevent users from making errors, the interface provides proper labelling and identification of icons. This, in turn, helps to reduce errors when users are performing these tertiary tasks. Icons and features on the interface are also properly designed and spaced within the design layout, in order to significantly minimize physical errors that could occur during input selection by the user.

6. ***Recognition Rather Than Recall:*** The interface is very simple and does not include complex features that can increase the cognitive load of the user or require long periods of visual attention. The use of several visual cues (i.e. real-world conventional icons/labels) and a consistent design screen layout, makes it easier for the user to recognize any feature and its function

7. ***Flexibility and Efficiency of Use:*** With increased use of the hands-free (voice command) interaction for task performance comes the demand for less touch-based interactions, and this allows for faster navigation of the interface. However, the precision target selection of icons and other functional elements embedded in the prototype (with touch-based interaction) captures the flexibility of use of the prototype's interface.

8. ***Aesthetic and Minimalist Design:*** The visual design of this interface commands simplicity that is devoid of clutter, providing a simple and aesthetically pleasing design look. Background color settings, icons, font size, layout and typography have all been given a lot of thought to provide a attractive feel to the prototype.

9. ***Help Users Recognize, Diagnose and Recover From Errors:*** Error messages are expressed in plain language to ensure nothing is lost in translation when performing a task on the interface.

10. ***Help and Documentation:*** Ideally, navigating through the interface to perform a task should be intuitive without having to resort to documentation or a manual instruction booklet. Gesture based interactions on this prototype's interface are reduced to tap, drag and swipe gestures, in order to minimize unnecessary steps and ensure input selection focused on the user's task.

C. Prototype Design Development and Concept

A four-step human cognitive architecture model was used for the prototype (Figure 3). This essentially served as a mental model of the process, and mirrored the mechanism by which the driver/user would input data for the tertiary tasks, process the data (prototype functionality), and store the processed data (based on recognition not recall).

D. Design Wireframes

The following section details the technical specifications of the IVIS high-fidelity prototype built for this research project.

The screen resolution of the prototype display is 1360 x 737 pixels. The incorporation of a high-resolution display provides crisp and easy-to-see images that essentially improve the driver-to interface interaction.

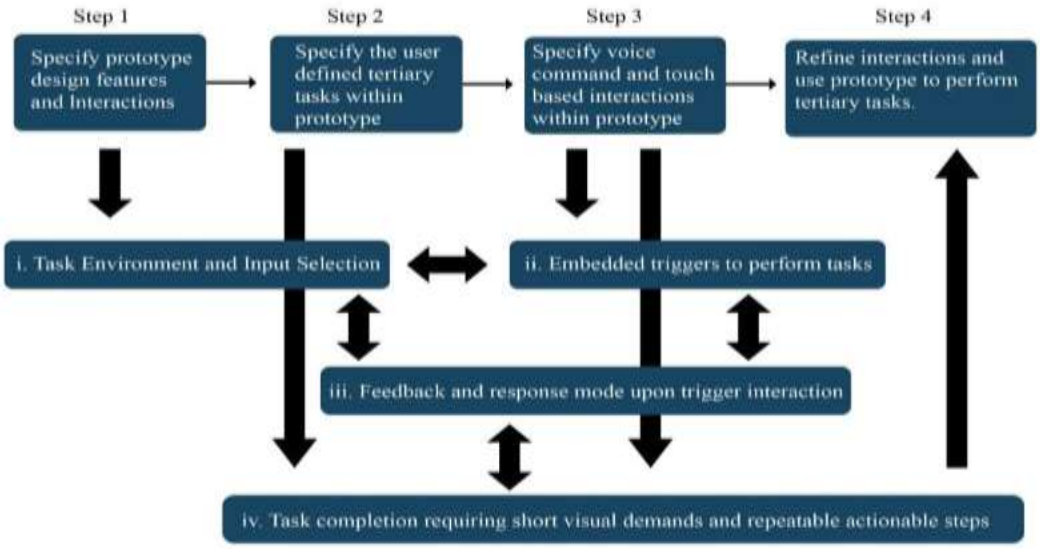

Fig. 3 Shows the concepts behind prototype structure and development [13]

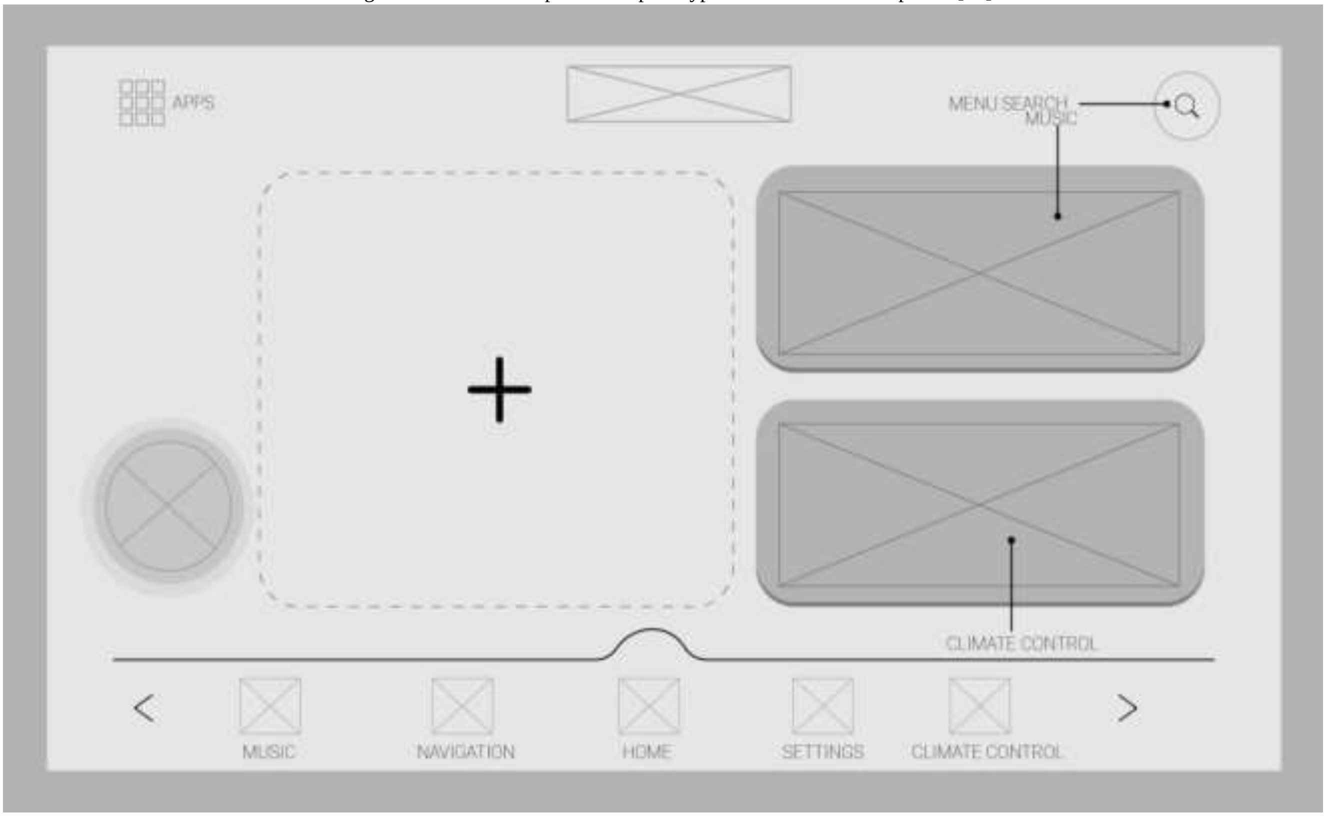

Fig. 4 Prototype Wireframe of Infotainment Home Menu

Fig.5 Static Image of the Prototype Infotainment Home Menu

Other specifications and features embedded in the prototype's functional interactions include a touch-based menu, hands-free/voice command interaction feature. The prototype also houses multiple major infotainment applications, such as a music player, navigation system, home/landing menu with car information and application widgets, settings and climate control.

The first screen the driver/user encounters when interacting with the prototype is a "welcome" page. The welcome animation is seamlessly timed and also leads to the next screen prompting the user to input an action by tapping the button on the bottom right corner of the touch screen display.

A glowing effect on the navigation buttons serves serves as an indicator and clear visual cue on the users next actionable and affordable steps. The main (home) screen of the IVIS interface is shown as both a wireframe and final version in Figures 4 and 5.

The addition of the "tertiary task information instructions" as one of the screens in the prototype is a temporary add in this current interface version (Figure 6). This is to ensure the continuous flow and walkthrough of the prototype by users/participants for the purpose of this research study and task completion experiment.

This information page prompts users to go to the infotainment "Home" menu. To ensure accessibility and proper usability of an interface it is not enough to include only text or verbal cues. The inclusion of these visual cues, icons and hierarchical elements (i.e. distinction in font-size and type) in an interface helps with memory retrieval and informs the user what to do next in an intuitive manner.

The utilization of the screens real-estate when designing the GUI layout is essential and is in-line with Nielsen's usability design guideline regarding the visibility of a system. The user will visibly be able to see their task operation and activity being performed on the interface without any obstruction or inconvenience from poor design layout or clutter.

The *dark mode* of the interface allowed the integration of neomorphism, which is a modern iteration style for icons using subtle shadows and realistic textures. This allows the user to easily distinguish the icons and gives their form a sense of depth. Some of the several benefits in using a dark mode color theme include; the ability of the design to reduce eye-strain in low light conditions. Recent research, also suggests that in the case of modern screens it will conserve energy and resource power.

The features embedded in the home menu afford the driver/user to seamlessly perform the tertiary tasks assigned. The hands-free gesture (voice command feature) affords the user to open the music player and select a song of their choice, thus reducing the over-dependence of touch screen selection. The performance of Task 1, for example, necessitated the use of a hands-free gesture (voice command), and hence required little to no major cognitive effort (Figure 6).

The music player's split design layout ensures full navigation, input selection and task performance within a consistent interface (Figures 7 and 8).

For design consistency, it was important to translate the split screen design from the music player to the climate controls (Figures 9, 10 and 11). Since recognition is better than recall, this reduces the cognitive effort of the user in grasping the concept of the page. The slider controls afford dragging the controls as a form of input selection to a desired temperature setting, in this case 62 degrees F as assigned by the task (Figure 11).

Fig. 6 Task Information Page

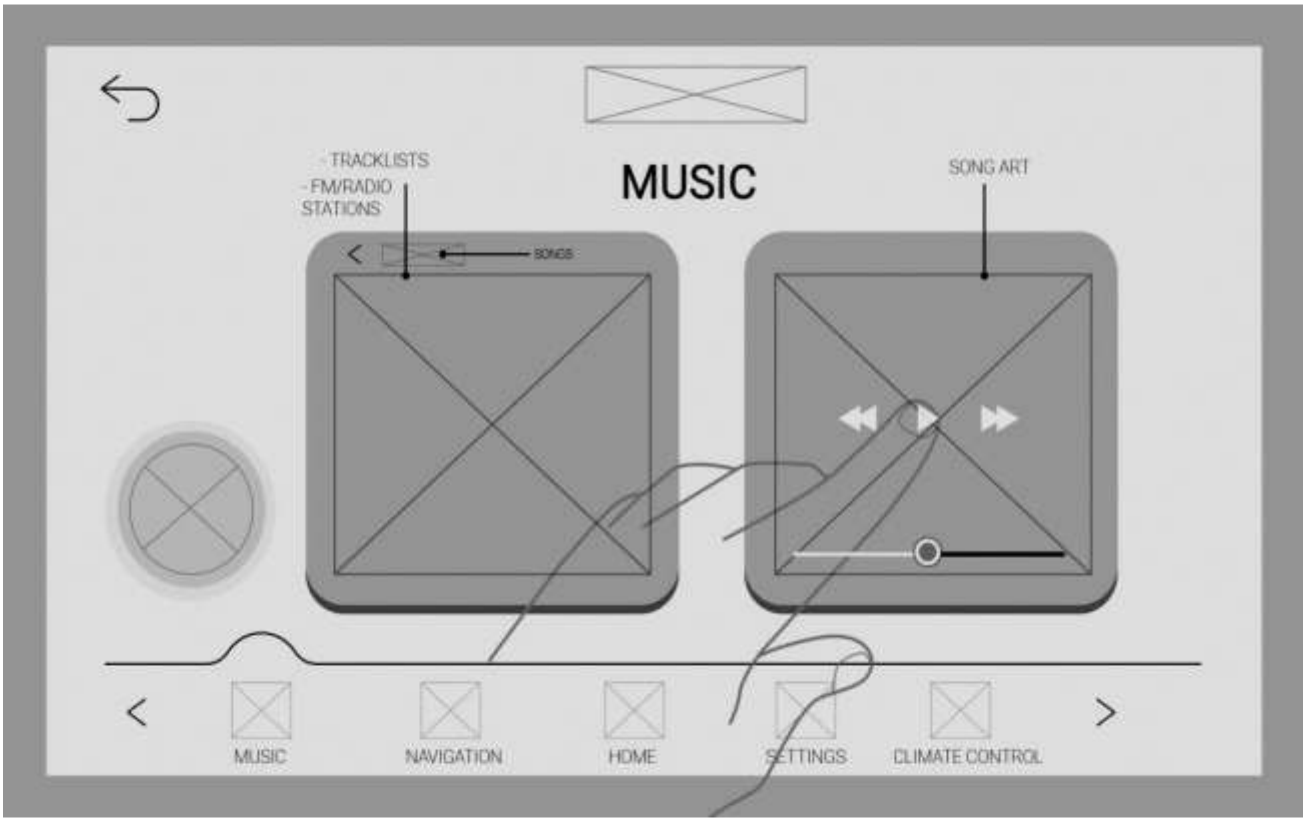

Fig. 7 Prototype Wireframe of Infotainment Music Player

Fig. 8 Static image of Prototype Infotainment Music Player

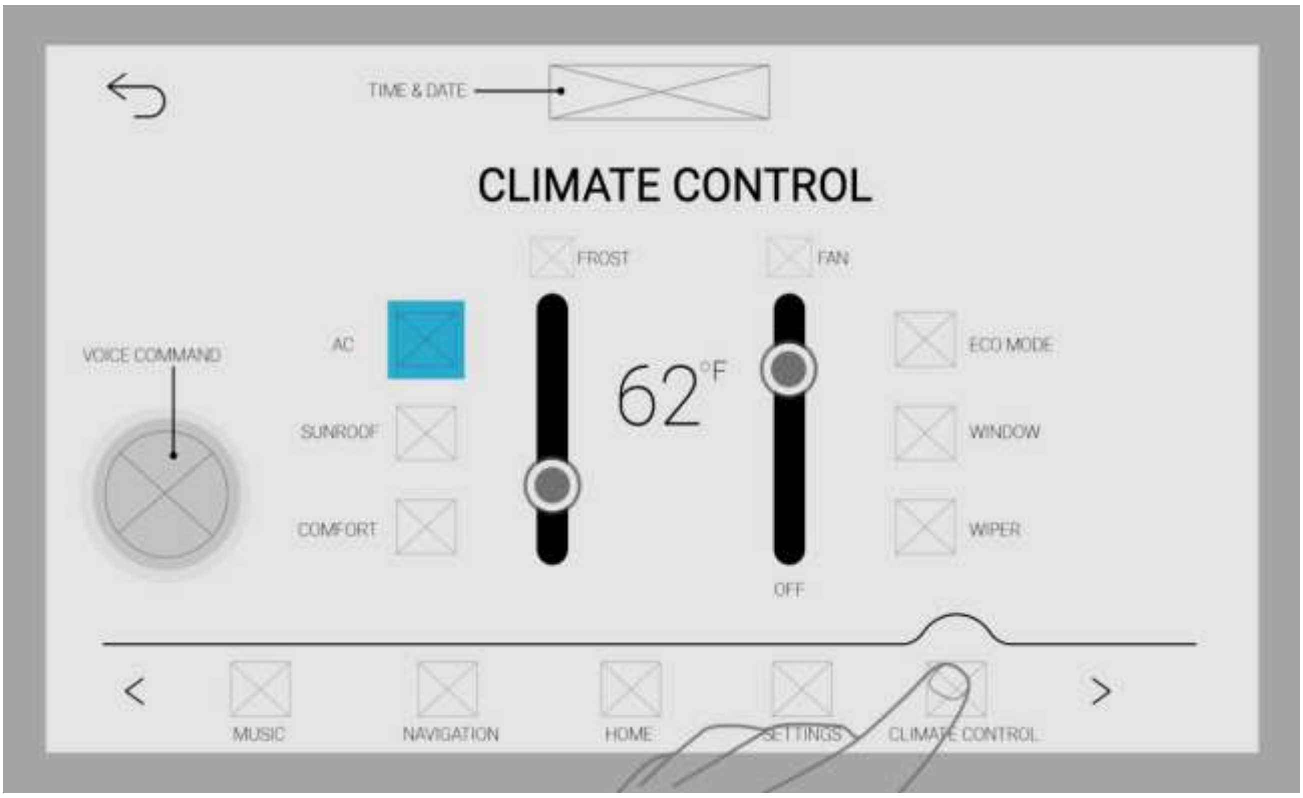

Fig. 9 Prototype Wireframe of Infotainment Climate Control

Fig. 10 Static Image of Prototype Infotainment Climate Control (Before Task Performance)

Fig. 11 Static Image of Prototype Infotainment Climate Control (After Task Performance)

V. DISCUSSIONS AND LIMITATIONS

The goal of this study was to develop a modern automobile infotainment menu interface prototype that seamlessly supports the performance of tertiary tasks, using visual, hands-free (voice-command) and gestural based interactions. This design operates as a proof of concept aimed towards automobile manufacturers, demonstrating that the range of design in infotainment interfaces can be expanded without compromising on comfort, driver safety and automobile user experience. The prototype also shows how a design can draw from a review of topical and scholarly works from relevant subject disciplines, coupled with knowledge of usability constraints that serve as design guidelines.

The prototype's interface features a wide screen with a high-resolution display affording the user a high degree of visual clarity when performing tertiary tasks. The landing screen of the interface features a simple layout, with a main menu filling the entire interactive surface. All functional applications/features are placed horizontally at the bottom of the screen allowing directional gestures to be used when selecting a feature. This helps to reduce any chance for obstruction (from other features) that may occur during input selection.

Other interface features include hierarchical menus and multi-functional control devices, which have been shown to potentially increase complexity and visual demand [11]. Voice command features enable the user to perform music and audio selections as well as return home to the 'home menu' of the prototype. This multimodal combination of both voice command and gestural-touch based interaction on this prototype makes it easier for users to perform tertiary tasks.

It is important to acknowledge that any in-car-infotainment system is usually operated within a highly dynamic environment. Thus, the way the user utilizes certain features depends upon the personal preferences within the individual environments [13].

In future research, there are certain design constraints and considerations that need to be factored into any potential development of an automobile infotainment menu prototype such as this. These (in no particular order include):

- **Ergonomics:** There needs to be a consideration given for users driving in bidirectional traffic and allowances for the interior specifications of different vehicles that utilize either left-hand drive or right-hand drive.
- **Mobility:** Future prototypes should aim to include other gesture-based supported interactions, and also individual allowances for users with physical disabilities.

The prototype for this research study, was designed and developed in Adobe XD. The observed performance of the two tertiary tasks scenarios described in this paper (i.e. for entertainment and comfort) can be assessed as users perform the assigned tertiary tasks on this high-fidelity prototype. The tertiary tasks assigned were single action tasks, neither of which required a significant interaction time. In any future research based on this prototype, it would potentially be useful to see the impact of users being assigned longer tertiary tasks, with several evaluation criteria.

In the automotive environment, the usability of any dashboard interface depends primarily upon the cognitive load caused by the interaction [13]. Therefore, for future research, evaluating the performance of the tertiary task load using a well-defined suitable metric (such as the Nasa Task Load Index questionnaire), will improve the assessment of the subjective workload of the tertiary tasks performed by the user. In the case of the Nasa Task Load Index questionnaire, this would be based on a weighted average of the user's answers to questions concerning the mental, physical and temporal demand as well as the performance, effort and frustration with the tertiary task performed while interacting with the prototype.

Assessment of the usability by ISO 924:11 (this is based on measures of effectiveness, efficiency, and satisfaction) could also be used as a criteria for the user-based evaluation of the prototype. Also, a metric that measures the visual appeal and attractiveness of the prototype's interface (for example, an AttrakDiff questionnaire) with questions covering both the pragmatic and hedonic qualities of context-aware features of the prototype would be useful. Additionally, the overall effectiveness of any future study could be measured and evaluated using a System Usability Scale (SUS) score.

VI. CONCLUSION

In conclusion, this study demonstrates a prototype approach to inform design improvements for an in-vehicle infotainment system menu interface with visual, hands-free (voice-command) and gestural-based features, in order to improve automobile driver safety and experience when performing tertiary tasks.

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