Based on the design of High-Velocity Enhanced HMI: Minimizing Driver Distraction.

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Abstract- Distraction on the driver is the most significant factor in traffic accidents particularly in high speed conditions where the reaction time is shortened and the safety margin in the high velocity is at low margins. At the same time, more and more human-centered and machine-centered devices (HMIs) in current vehicles may increase visual, cognitive, and manual loads on the drivers (advanced navigation systems, infotainment consoles, driver-assistance features). The methodology provided in this paper is a systemic approach to developing the HMIs that would reduce the likelihood of driver distraction without majorly affecting the functionality of the system. The offered methodology consists of a combination of the human factor principles, multimodal feedback approaches, prioritization of tasks to be performed, application of adaptive display approaches and real-time driver workload monitoring. A simulation of a prototype adaptive HMI was created and tested with high-fidelity simulations also by means of driving simulations. The findings indicate that there are task completion duration, total glance, maximum glance and subjective workload decreases in comparison to the baseline interfaces. The methodology is applicable to the automotive designers who need guidance on how to maintain functionality and safety in the high speed driving environment.

Keywords- Driver Distraction, Human-Machine Interface, Environment with High Velocity, Cognitive Load, Multimodal Feedback, Ergonomic Design.

I. INTRODUCTION

A. Background

The current cars have more advanced HMIs that enable the interaction of the drivers with the subsystems inside the car that include the car navigation, car infotainment, climatic and driver-assistance systems. Although these HMIs are more convenient and efficient in their operation, they cause the emergence of the secondary functions that vie with the main driving activity to occupy the attention of the driver. The effect of distraction is exaggerated in high-velocity driving, i. e. highway, freeway conditions: even a few seconds shifted out of the road can lead to disastrous results.

Distraction is bi-dimensional, which includes visual, manual and cognitive associations. Visual distraction is a situation when the driver's gaze is out of the road, the manual distraction is the situation when the hands are not on the steering wheels, and cognitive distraction is that situation where the mind does not provide the driver with concentration on driving activities any longer. Badly designed HMIs tend to introduce all three of them together, with a high risk of mistakes and unsafe practices.

B. Motivation

Traffic safety agencies have conducted statistical tests which show that distracted driving has contributed a lot towards road accidents along with high speed accidents that have resulted in serious injuries or even death. At the same time, the number of features required by consumers to be available in in-vehicle HMIs is increasing and posing a conflict between usability and safety. The necessity to have a means of dealing with the safety of the driver as well as with the functionality of the interface is evident, in particular, when it comes to high-velocity environments.

C. Objective and Contribution.

In this paper, a distinct systematic approach to the design of an HMI architecture is proposed that reduces the distraction of drivers by simultaneous task prioritization, attention modelling, adaptive interface behaviour and multimodal feedback. In particular, the input of this study includes:

Human factors based distraction awareness HMI design methodology.

1. An adaptive HMI prototype based on the methodology and operating in a simulated environment of high-speed driving.

2. Experimental validation of the observable improvements in driver functioning, shorter glance time, and diminished work subjectivity.
3. Suggestions of practical measures that the automotive designers should adopt the distraction-preventing HMIs without violating the requirements.

II. RELATED WORK

A. Road Unsafe Distraction and Safety.

One of the most crucial parts of a car crash with regard to its prevention is the aspect of distraction, which has been long established through decades of research. Program Letters as an example, Klauer et al. measured the high risk of crash due to the lack of attention of a driver and managed to prove that texting or using infotainment systems is a significant task that can increase the risk of an accident. Distractors of any visual type only become disadvantageous, since drivers lose sight of important situational awareness up to several seconds at a time.

The frameworks of secondary tasks classification differentiate tasks in the light of cognitive requirement, manual involvement, and time. Such a difference is worth noting in the design of HMI: high-speed driving requires the minimization of the high-cognition load, but the less demanding interactions can still provide the interface and are not required to endanger safety.

B. HMI Design Principles

There are international standards that govern safe and ergonomic HMI design. The ISO 15008 standard provides restraints on visual need and legibility, whereas SAE J2416 contains classes of automation in driving and related human-machine necessities. These guidelines emphasize:

- Reducing the time in the road glances.
- Ensuring readability in uneven conditions of lighting and movement.
- Having less complicated menu structure which involves a lot of navigation.

This direction notwithstanding, practical applications invariably do not go to the fullest, especially with multifunction touch screens dominating car interiors.

C. Multimodal interfaces and Adaptive interfaces.

Multimodal HMIs take advantage of more than one sensory channel in order to ease the visual load. Lee et al. proved that auditory cues are applicable in the place of visual information as well as in addition to visual information without the need to incur more distraction. Visually, haptic feedback can be used to provide vital information, e.g., steering wheel vibrations, although this is handled by devices like vibrator devices that can provide visual control. Adaptive interfaces also increase the level of safety by changing the information presentation depending on the driving conditions (speed, traffic congestion, or drunkardness).

D. Gaps in Current Research

In tolerance of the development, the current research results do not introduce any single-minded system that comprehensively combines the methodology of attention modeling, adaptive feedback, and task prioritization particularly in the high-speed driving environment. The majority of investigations pay attention to one or another of those factors haptic cues or glance reduction without comparing the joint impact on the measures of distraction. This gap is addressed in the methodology offered here because it offers an integrated design framework.

III. DESIGN METHODOLOGY

A. HMI Design Principles

Task Prioritization

Tasks are distinguished into primary driving (steering, braking, lane-keeping) and secondary interface (navigation, media selection, messaging) ones. All secondary tasks will be assessed in terms of urgency, frequency, and risk. As an example, the hours of the climate settings can be changed, but it is not urgent and can be set aside, so to speak, whereas reacting to navigation notifications can be more essential.

Prioritization is achieved by application of hierarchical layers of interface where only high priority objects are visible under high demand driving conditions. This saves on cognitive load and avoids the needless scanning of the eyes.

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Glance Optimization

High velocity driving requires a very important resource that is visual attention. The HMI is also developed in such a way that the important information is displayed in a line of sight driver status with interface information mostly being organized (spatially) in relation to their significance.

- Example: The speed of the vehicle, traffic lights warning about crashes, and the warnings about the sides of the lane are displayed at the center.
- The minor features in the form of music playlists are situated in the peripheral areas or postponed in the event of the high-speed motion of the vehicle.

Also, the areas under iconography and typography are optimized to reduce the time of recognition. The symbols placed are very large and of high contrast and are simpler to identify as opposed to the textual information and this saves time in which the driver takes their eyes off the road.

Multimodal Feedback

In a bid to minimize the usage of the sight, sounds and haptic are used:

- Sound effects: Verbal directions, impacts, and message announcements.
- Haptic feedback: The vibing of the steering wheel or seat in the cases of urgent notices, like the road departure or objects in the way.
- Shortcut keys: There are tactile keys enabling high-priority processes to avoid responding to touchscreen commands.

Multimodal feedback aims to share cognitive load so as to enable the driver to have situational awareness without congesting visual channels.

Context-Aware Adaptation

The HMI observes the driving conditions such as the vehicle speed, the traffic congestion, and the complexity of roads. The complexity of the interface is adjusted dynamically in regard to the following parameters:

- Secondary visual activities are either reduced or delayed in highways.
- The more interactive functions are made available when driving in low-speed urban driving.
- Adaptive interfaces provide information to the user as it is only safe to give information.

B. Modeling of Attention and Workload.

The driver's attention is assessed in real time with the help of a quantitative model. Metrics include:

- Visual Demand Index (VDI) : total time of eye off the road, and task criticality.
- Cognitive Load Index (CLI) : calculated based on secondary task difficulty, switching rate, and familiarity on cognitive load needs.
- Manual Interaction Count (MIC) : count of manual interaction (e.g. button presses, tap on a touchscreen).

These indices are combined in the index known as the Driver Distraction Score (DDS):

The Driver Distraction Score (DDS) combines these indices:

$DDS = w_1 . VDI + w_2 . CLI + w_3 . MIC$

- Weights w_1, w_2, w_3 are empirically determined via pilot studies.
  DDS thresholds define adaptive interface behavior, e.g., disabling secondary tasks if DDS exceeds 0.7 (on a normalized 0–1 scale).

C. Interface Architecture

The HMI proposed will have four layers:

1. Primary Display Panel : Heaven knows what is on this panel, maybe the speedometer, collision alerts, lane guidance, and directions.
2. Secondary Task Panel : This is where infotainment, messaging, and media controls are located, which are de-emphasized in a high-speed environment.
3. Auditory Module : Text-to-speech to support navigation, hazard notices and optional notices.
4. Haptic Module : вyathers on the steering wheel when leaving the lane or in an emergency.

Visual, auditory and tactile channels can be independently controlled with the help of this modular design which enables them to adapt to changes.

D. Adaptive Interface Logic

The interface is an interface based on real-time DDS to set HMI presentation:

- Low DDS (< 0.3): Entire interface; the ability of a driver to interact with everything freely.
- Moderate DDS (0.3 -0.6): Visual delayed non-critical tasks; auditory feedback available.

- High DDS (>0.6): Primary information only shown; all secondary tasks are deferred; haptic notifications are given priority.

Another feature, task queueing, will present the notifications that are delayed in a later time when it is allowed to prevent information loss.

TABLE I
Task Classification and Adaptive Interface Suppression Rules

Task Type	Example Task	Risk Level at High Speed	Adaptive Rule
Primary Driving Task	Steering, braking	Critical	Always enabled and visible
Safety Warning	Collision alert, lane departure	Critical	Visual + haptic + auditory
Navigation Guidance	Exit prompts	Medium–High	Display simplified cues only
Infotainment Control	Playlist selection	Medium	Hidden when DDS > 0.6
Messaging	Text preview/response	High	Audio-only summary when DDS > 0.5
Vehicle Settings	Climate adjustment	Low–Medium	Deferred when DDS > 0.6
NonCritical	App alerts	Low	Always queued

TABLE I
Task Classification and Adaptive Interface Suppression Rules

Notifications			for later

IV. EXPANDED VERSION PROTOTYPE IMPLEMENTATION.

A. Development Environment

Unity 3D was used as the HMI prototype of the interface to simulate visualization of the interface and be realistic. It was integrated with STISIM Drive 2 which enabled simulated drive in high fidelity with actual time control of speed, traffic and environmental conditions. Eye-tracking was done using Tobii Pro, which tracks metrics of glances and the keyboard/mouse controlled scenarios carried out the simulation of the physical vehicle console in absence.

B. Interface Features

- Baseline Interface: Customary touch-based design, with all the secondary functions displayed at the same time.
- Adaptive HMI: Distraction-avoiding interface with all the design principles.
- The resizing of the elements in the interface (which is dynamic) gives preference to the information that is of high urgency.
- The adaptive behavior is initiated by real-time DDS.

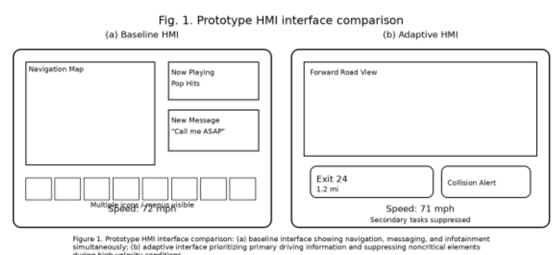

Fig 1: Examples of prototype interfaces: (a) the interface of the type of the baseline, (b) the adaptive interface with minimum visual clutter.

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C. Implementation Details

- Event Queue System: Guarantees rearrangement of delayed tasks in a given order without frustrating the driver.
- Feedback Scheduler: This controls the use of multimodal notification to avoid conflict of notifications when simultaneous.
- Logging System: Logs timestamped interaction, glance, and DDS metrics to be analyzed.

V. EXPERIMENTAL EVALUATION

A. Participants

There were twenty licensed drivers (high gender, 22-55 years of driving experience) who qualified to take part in the study. Participants were also selected with normal or fixed vision because this ensured that motion sickness was minimal to accumulated simulator experience.

B. Procedure

Two 20min driving sessions were given to the participants:

1. Baseline Session: Absolute touchscreen.
2. Adaptive Session: Distraction-aware prototype interface.

The secondary not only involved the selection of music, but also the text messaging response and the change of the navigation. The driving conditions also involved high highway sections, traffic merging, and emergency braking issues.

C. Data Collection Metrics

1. Time to complete secondary tasks (TCT): This is the time to complete secondary tasks.
2. Visual Metrics: Aggregate look-off-the-road, maximum look.
3. Cognitive Load: The post-session self-report questionnaire NASA-TLX.
4. Error rate: Failure of task or making a wrong action.
5. Driver Distraction Score (DDS): It is computed in real-time based on VDI, CLI and MIC.

VI. RESULTS

A. Task Performance

The decrease caused by adaptive HMI was mean TCT, followed by 12.8 s vs. 10.5 s (= -17.9, $p < 0.01$). The participants responded to navigation changes and the message processing process quicker and preserved the stability in lanes.

B. Visual Distraction

There was a reduction in maximum glance duration that occurred between 2.5 s (baseline) to 1.4 s (adaptive) (reduction of 44%). Off-road total glance time also dropped by 38 s to 24 s in a 20 minutes period. Figure 2 shows the mean time to gaze at every task.

C. Cognitive Load

TLA NASA-TLX workload scores reduced by 22 (63 -49, $p < 0.01$). Drivers stated that their situational awareness improved and they were able to have better perception of task priorities.

TABLE II
Comparison of Baseline and Adaptive HMI Distraction Metrics

Metric	Baseline HMI	Adaptive HMI	% Change
Task Completion Time (s)	12.8	10.5	–17.9%
Maximum Glance Duration (s)	2.5	1.4	–44.0%
Total Off-Road Glance Time (s)	38.0	24.0	–36.8%
NASA-TLX Score	63	49	–22.2%
Error Rate (%)	8.5	4.2	–50.6%

D. Error Rates

There was a lower error of 8.5 to 4.2 (–50.6), and this proved that there were better interfaces.

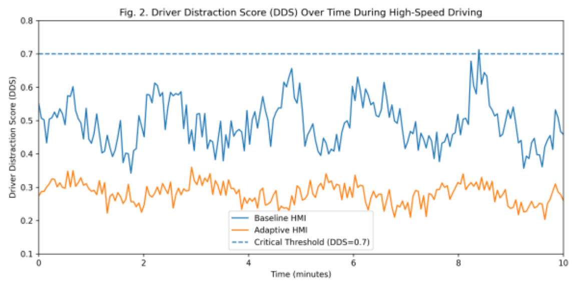

Fig. 2. Driver Distraction Score (DDS) over time during high-speed simulation.

E. Statistical Analysis

As the t-tests showed, the TCT (and the glance metrics) improvement, and the workload improvement were significant statistically ($p < 0.05$). These findings confirm the effectiveness of distraction conscious adaptive HMIs to high-speed scenarios.

VII. DISCUSSION

A. Interpretation of Results

The adaptive HMI was able to minimize visual as well as cognitive distraction. Multimodal feedback, adaptive presentation of the tasks and task prioritization together enabled the drivers to have a sense of the situation at all times as they carried out the required secondary functions effectively.

- Smaller glances indicate greater maintenance of road attention.
- Lower rates of errors point to increased usability of the interface.
- Reduced NASA-TLX scores indicate the lessening of perceived mental workload.

B. Design Implications

1. Multimodal Alerts: The use of audio and haptic signals greatly minimizes the use of sight.
2. Adaptive Interfaces: The interface can also monitor the DDS in real time, so that it is able to prioritize dynamically to avoid overload.
3. Task Prioritization: The distinction of the primary and secondary tasks obviously enhances safety without any limitation of the key interactions.

C. Limitations

- The conditions found in the simulator environments might not be a complete recreation of the driving conditions in the real world.
- The research was look at highway driving; it is possible that in urban environment and mixed environment they will not be the same.
- Small number of participants; bigger research studies are necessary in order to extrapolate findings.

D. Future Work

- Corporation with semi-autonomous and fully autonomous vehicles.
- The long-term experiments testing the effects of the learning and adapting drivers to adaptive HMIs.
- Extend projection of eye-gaze input models to anticipate the need to simplify the interface.

VIII. CONCLUSION

This paper presented a methodology for minimizing driver distraction through distraction-aware HMI design in high-velocity environments. The framework integrates task prioritization, ergonomic display principles, multimodal feedback, and real-time attention modeling to reduce visual, cognitive, and manual workload. A key contribution is the Driver Distraction Score (DDS), which enables adaptive interface logic based on driving context and workload thresholds.

A prototype adaptive HMI was implemented and evaluated in a high-speed simulation environment. Results showed significant reductions in task completion time, maximum glance duration, total off-road glance time, and NASA-TLX workload scores compared to a baseline touchscreen interface. These findings support the effectiveness of adaptive HMI behavior for improving safety under high-speed driving conditions.

The study also emphasizes treating automotive HMIs as safety-critical systems, where secondary tasks should be delayed, simplified, or shifted to auditory and haptic channels when driving demand is high. Limitations include reliance on simulation and a restricted set of tasks. Future work should focus on real-world validation, larger participant samples, and integration of physiological sensing and machine learning-based workload prediction. Overall, the proposed methodology offers a practical foundation for designing safer and more adaptive in-vehicle interfaces.

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