Affective Computing and Biofeedback in Human Vehicle Interaction

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***Abstract*—Monitoring the driver's state of mind and emotions is crucial while driving, as a negative state can negatively affect driving performance and lead to accidents. With the increasing automation levels in cars, safety has become a major concern for manufacturers.**

The goal of this seminar project is to conduct research on monitoring the driver's state and emotions. This research will focus on providing feedback to the driver through various sources such as music, light, empathic speech, biofeedback, temperature, and relaxation techniques to prevent accidents. Literature review on current methods has shown that biofeedback can improve the safety and mental state of the driver in autonomous cars. The article will review the latest proposed methods and evaluate their strengths and limitations. By doing so, the reader will gain an understanding of advancements in emerging directions to improve human safety.

Furthermore, this article will not only introduce the methods and comparison among them, it will endeavour to give insights about difficulty in data collection, conducted experiments and shed light on future directions.

Keywords – Biofeedback, Emotion Regulation, Human-Vehicle Interaction, Empathy, Emotional and Affective state

Fig. 1. **Vehicle-Car Interface system**. Sensor 1 for capturing the driver's face and audio, Sensor 2 for capturing the environment and audio, Sensor 3 for capturing voice recordings, GPS, and acceleration, and Sensor 4 for capturing the driver's heart rate, electrodermal activity, and skin temperature. Such a system is deployed inside the car and the data is captured to understand the emptional triggerss and how we can better regulate them.

I. Introduction

In recent years, Artificial Intelligence (AI) [1], [2] has made significant strides and its impact is being felt in various fields. One of the major advancements has been the development of systems and sensors that can capture user awareness through various modes such as voice assistants, gesture recognition and intelligent user interfaces. The interaction between humans and computers can greatly enhance the user experience and enable natural interactions with devices [3], [4], [5], [6].

In this paper, we delve into the field of affective computing and biofeedback in human-vehicle interaction. Affective computing refers to the interface mechanism that detects the emotional state of the user and processes their needs in an empathetic manner. These interfaces are noteworthy as they sense, interpret, adapt and potentially respond appropriately to human emotions. Research in this field began in the late 20th century by [7], and has been focused on sensing emotions through psycho-physiological measures, speech analysis, or facial expressions. Applications for this technology have been thought of in various fields, and among them, affective systems for in-car usage have been seen as a potentially beneficial implementation as emotions can have a significant impact on road safety.

Recently, a number of methods have been proposed to use AI assistants to detect emotions and gestures and interact with drivers in order to improve the overall experience in human-vehicle interaction. However, many of these methods focus on a single input domain, such as light [8], [9], speech [10], [11], music [12], [13], breath [14], [15], or emotions [16], [17], [18], without providing a comprehensive comparison of different interfaces. Our objective in this work is to address this gap by offering a fair and meaningful comparison of various biofeedback systems, and identifying the challenges and inherent biases in designing a new biofeedback testing mechanism.

The paper is organized as follows: Section 2 provides an overview of related work, Section 3 details the latest methods by grouping the interfaces with similar functionality, Section 4 presents brief experiments that capture the essence and validate the modern interfaces, and finally, in Section 5, we discuss future work and provide pointers for improvement in human-vehicle interaction through biofeedback.

II. Related Work

In this section, we will give a brief overview of the current trends in human-vehicle interaction that are relevant to our project. For a more thorough examination of the field of affective computing and its applications in other domains, such as stress management, group collaboration, and self-learning, for a comprehensive overview of these areas, we suggest referring to the works of [19], [20], [21].Affective computing and biofeedback have been widely researched in recent years to improve human-computer interaction. Various methods have been proposed for detecting and interpreting human emotions through psycho-physiological measures, speech analysis, and facial expressions. Some studies have focused on the use of affective computing in in-car systems to improve road safety by monitoring driver emotions and providing appropriate feedback.

Previous research has examined the impact of different emotional states on driving. For example, the study by [22] looked at emotional triggers that can lead to accidents on the road. They conducted experiments with 33 drivers and found recommendations for potential future interventions. Additionally, [23] conducted an experiment on angry drivers and found that negative emotions significantly increase the likelihood of accidents. To reduce accidents, it is critical to monitor the emotions of drivers. Other studies, such as [16], [17], have shown that sadness and anger can also lead to longer driving times and increased accident risk.To prevent accidents, it is important to monitor the emotional state of drivers. In [12], a study found that music can help reduce the emotional impact on drivers. The study by [13] proposed a technique to release negative emotions through the use of music by introducing a framework that connects driver emotion recognition and adaptive music playing system. Additionally, the study in [24] reviews literature on the impact of emotions on driver behavior and the state of emotion regulation in vehicles. On the contrary, we provide a comprehensive review not limited to emotions but also extend the analysis to different sensors like music, temperature, voice, music, stress aids, and thus provide a first work to the best of our knowledge.

III. Method

In this section, we will be thoroughly examining the methods for capturing drivers' state and emotions and the various techniques that have been proposed using different modes. Our aim is to provide a comprehensive understanding of the process. To achieve this, we will start by briefly discussing the overall interface system in the setup and then move on to the topic of emotion regulation. We will delve into each emotion, paying special attention to mitigating any negative effects.

TABLE I
We categorize the human-vehicle interface system basing on the sensor type and report the main paper here along with year and details about the experiment.

Mode	Year	Interface	Experiment
Music	2014	Validating driver anger	53 drivers
	2016	Mitigate negative emotions	30 drivers
Speech	2013	communicate with the driver	15 minutes
	2005	Improve driver performance	60 drivers
Light	2014	overlake the car or not	5 persons
	2019	emotion-based lighting	12 drivers
Relaxation	2019	slow breath	60 drivers
	2018	Breath slowly	24 drivers
Temperature	2017	Reduce fatigue	33 drivers
	2017	by cooling-effect	3 drivers

Empatatic Car Interface: For the sake of familiarty, we introduce a sample car-interface system that is essential part in most of the studies. For example, in [18], the authors demonstrated the use of various interfaces and sensors to capture the driver's state within the vehicle. As illustrated in Figure 1, the sensors used in the experiment includes: Sensor 1 for capturing the driver's face and audio, Sensor 2 for capturing the environment and audio, Sensor 3 for capturing voice recordings, GPS, and acceleration, and Sensor 4 for capturing the driver's heart rate, electrodermal activity, and skin temperature. Such a system is deployed inside the car and the data is captured to understand the emptional triggerss and how we can better regulate them. As we can observe, the data collection is extremely time-consuming and jusstifiaibly, most of the works that we will discuss in this paper has inherent bias as they are small-scale. We will now introduce the emotional regulation in vehicles.

Emotion Regulations in vehicle:

The area of emotion regulation in vehicles has been the focus of several research studies. In two of these studies, the authors summarize the advancements in this field. In the first study [24], the authors conducted a literature review on the effect of emotions on driver behavior and analyzed the state of emotion regulation for drivers in vehicles. They organized the articles into categories such as emotion detection in cars, the impact of emotional states on driving, triggers of emotions while driving, and methods for regulating emotions. The second study [23] investigated the effects of drivers' state and emotions during driving. The authors conducted an experiment on angry drivers and found that negative emotions significantly increase the likelihood of accidents. The importance of monitoring the emotions of drivers to reduce accidents was emphasized.

In addition to the above works, authors in [16] showed that sad driving is just as dangerous as angry driving and concluded that crying while driving should be avoided as it increases driving time. Both sadness and anger were observed to lead to significantly longer driving times to reach the same distance compared to a neutral emotional state.

It has been well established that negative emotions can lead to accidents while driving. To reduce accidents, various techniques such as music, speech, ambient light, interventions, relaxation techniques, and temperature control are used to prevent them. Emotions can be identified through facial expressions and body temperature, and vehicle conditions can be used to complement this information and mitigate negative emotions, reducing the risk of accidents. We will now breakdown each emotion and summarize the articles in the same theme and endeavour to bring the similarities and differences.

A. **Music:**

In this emotion subtype, the adaptive music system gathers information and regulates the emotions. For example, in [13], the information comes majorly three sources. First, the Driver System, which collects data on the driver's emotions through heart rate, skin condition, and self-reported emotion data, as well as their music preferences. Second, the Road System provides information on traffic and environmental conditions. Third, the Vehicle System provides information on the vehicle's status and driving performance. Based on the information collected, the music framework automatically matches music to the driver's emotions and plays happy or sad music accordingly, in order to alleviate negative emotions and improve driving experience.

Besides, the authors in [12] conducted an experiment with 53 drivers for 15 minutes after turning on music and found that anger was significantly reduced. We believe are significant findings and therefore, we show them in Figure in 7, it can be observed that the mean angry score before and after anger induction has significant difference. In this way, authors shown the angry score can be reduced by introducing the music-based empathy feedback.

B. **Speech:**

In the speech-based interface, it can help the cars to reduce accidents by providing drivers with assistance such as restaurant recommendations, advertising, call management, navigation, FM, and other interactions, without requiring the use of hands or eyes, allowing the driver to focus solely on driving. Authors in [10] has demonstrated that this can lead to a reduction in accidents. Moreover, in [25], the authors propose the detect the emotions through conversations in a simulated environment set up.

C. **Light:**

The study in [9] explores the potential of ambient lighting systems to increase driver comfort and provide non-distracting warnings in critical situations. The authors aim to design "Lumicons" or light patterns that can effectively communicate information to drivers. The study proposes two designs, the first being a static encoding system where three lights in the front left corner change color and brightness depending on the distance to a closing car. In the case of a driver changing lanes when another car is within a critical distance, the display will start flashing at full brightness. The second design is an adaptation of the moving dot at the door design, where a green light starts behind the driver and changes to red in front at a Time-to-Collision of 2 seconds. The intention of overtaking triggers a brightness increase.

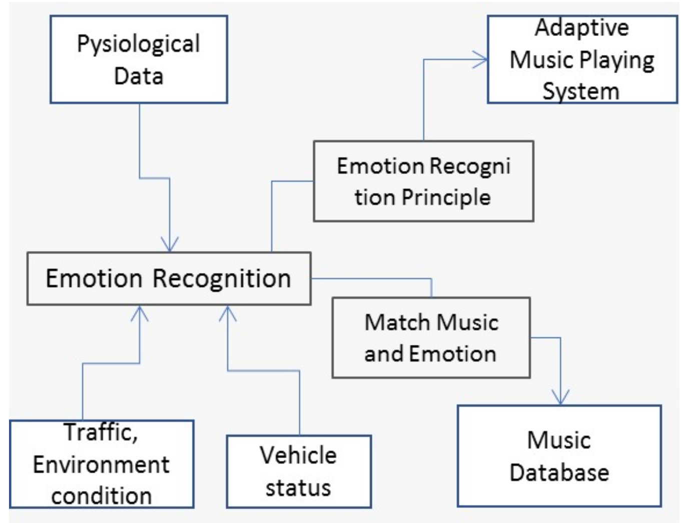

Fig. 2. **Adaptive music interface system.** The drivers emotions are regualted by three indepedent sources namely, driver system, road system and vehicle system. The information is then analysed by the emotion recognition system and then recommends the music based on the emotion detection.

Fig. 3. **Light-based interface to provide feedback.** Authors consider two lighting scenarios, the blue (left) and orange (right) ambient lighting conditions. The sensors were used to detect the driver's emotions while the ambient light was usedto influence driving behavior. Both light colors improved driving performance compared to a baseline ride due to their warning (orange) and calming (blue) effects.

The paper [8] focuses on the effect of ambient lighting color on human emotions and behavior in the context of human-vehicle interface. The authors selected two ambient lighting colors for their experiment: blue and orange. Blue lighting was chosen as it is related to vitality, energy, and power and is perceived as a calming and pleasant color that elicits little emotional arousal. On the other hand, orange was selected to increase arousal levels, as it is associated with a higher level of emotional arousal. The authors chose orange over red to differentiate the warm color stimulus from warning signals, such as traffic lights.

D. Relaxation Techniques::

In the study conducted by Balters et al. [14], the authors focused on evaluating the efficacy and safety of guided slow breathing interventions in a real-life driving scenario. This study represents a significant step forward from prior studies which were limited to driving simulators. The study was conducted with 40 participants and was designed to test the haptic guided breathing system under both stressed and non-stressed driving conditions. The results of the study were positive, with participants reporting that the intervention was helpful in reducing their breathing pace and perceived stress. Additionally, a visual inspection of the raw breathing waveform showed that most participants lowered their breathing rate, and early analysis of subjective user feedback indicated a positive acceptance of the system. Furthermore, the authors conducted a thorough analysis of the lane capturing videos and found no instances of lane departures. All participants reported that the system would be safe for real traffic applications, although there were some concerns raised regarding its use with drowsy drivers. The authors acknowledged that further analysis is needed before exposing commuters to the intervention on public roads.

We also summarize a study conducted by the authors in [15] on the effect of breathing. The study found that drivers preferred haptic over voice-based guidance for two main reasons: (1) haptic vibration patterns were perceived as less obtrusive and more relaxing than voice commands, and (2) continuous haptic feedback helped maintain a rhythmic breathing pace compared to discrete voice messages. The study demonstrates the potential of this new form of intervention to help users turn their daily driving time into a mindful experience, reducing stress and increasing psychological wellness.

E. Temperature:

A study in [26] aimed to mitigate driver fatigue. Past studies on the potential of thermal stimuli to reduce fatigue had inconclusive results, however, the study in question found that the duration of the thermal stimulus strongly affects perceived fatigue. A driving simulator study with 33 participants was conducted to investigate the effects of a 2-minute and a 4-minute thermal stimulus at 15 degree on non-sleep-deprived drivers. Results showed that a 4-minute stimulus led to increased sympathetic activity, lower subjective fatigue ratings, and preferred driving experience. However, the effect only lasted for 6 minutes after the stimuli. Future research should build on the identified benefits of a 4-minute cooling stimulus and focus on increasing its duration.

A study in [27] investigated the effect of cooling on cognitive fatigue for drivers on monotonous routes. A driving simulator study with 34 participants was conducted to compare physiological and vehicular data during cooling and control conditions. The results showed that cooling applied during a monotonous drive increased the alertness of drivers, resulting in lower sleepiness rankings, physiological indicators for increased sympathetic activation, and better driving performance. The study concluded that cooling has a positive short-term effect on drivers' wakefulness, with a cooling period of 3 minutes delivering the best results.

F. Stress:

In [18], the authors describe how driver stress can be measured through various interactions and how the information can be used to create new in-car interactions aimed at reducing stress and improving driver safety. Some of the potential interactions that can effect stress include adaptive music, an empathetic GPS, calming temperature, corrective headlights, and a reflective dashboard. The car may detect when the driver is overly stressed and recommend a more relaxing audio experience, or adapt the temperature to help alleviate stress-related sensations. The car can also compensate for the loss of peripheral vision that occurs during stress by adjusting the field of view of the headlights. Additionally, a reflective dashboard could provide physiological information to the driver to help them reflect on and manage their stress levels.

In [28], the authors explored three scenarios where a system needs to adapt to a stressed driver: driving in a packed city, before take-over requests in automated driving, and when unable to find a parking spot in manual driving. An expert workshop was conducted with five participants and 23 ideas were identified for mitigating frustration. Based on these ideas, four concepts for ambient light patterns were suggested for affect-aware systems. The patterns were designed to not be confused with warnings or common assistant systems and were partially derived from existing guidelines and best practices. It is important to note that only two external experts participated in the workshop, in addition to the authors, and the solutions proposed are based solely on ambient light.

G. External Factors:

The paper in [29] examines the influence of reappraisal affordances (the opportunities for reinterpretation of a stimulus) on emotion regulation choice. The authors conduct four studies to show that reappraisal affordances have stability across people and time and are not confounded with emotional intensity for a standardized set of picture stimuli. They then construct a context in which emotional intensity is separable from reappraisal affordances and show that reappraisal affordances can influence emotion regulation choice. The results of the study suggest that affordance ratings and intensity ratings for stimuli used in prior studies covaried, but the stimulus sets used were not appropriate for testing the effect of reappraisal affordances. The authors also find that the predominant emotion for high affordance vignettes was anger and the predominant emotion for low affordance vignettes was disgust.

IV. Results

In this section, we aim to present a comprehensive overview of the experimental setup and key findings from relevant studies within the human-vehicle interaction literature. Our focus is to present the most significant results that help to establish trust and safety in human-vehicle interactions. We aim to provide a concise summary of each experiment and illustrate its contribution to the overarching goal of improving the trust and safety of human-vehicle interactions. By presenting these key results, we hope to provide a clear picture of the progress made in this field and highlight areas for future research.

How different factors relate to positive or negative triggers: In [22], the authors conducted an experiment involving 33 participants, divided into four groups based on different emotional triggers. As shown in Figure 4. They found that participants in Group 1 (Traffic Driving Task) experienced mostly negative triggers related to the interaction between traffic and the driver. Group 2 (HCL & Navigation) participants received mostly negative feedback due to their interaction with the car. Participants in Group 3 (Vehicle & Equipment) received mostly positive feedback, with many reporting excitement when shifting gears and accelerating. Group 4 (Environment & other) participants reported positive triggers due to the good scenery and clouds they saw while driving.

This study highlights the importance of considering different triggers that can evoke different emotions in drivers, which can have an impact on their behavior and decision-making while driving. The findings from this study suggest that the design of human-vehicle interfaces should take into account the potential emotional triggers and incorporate feedback mechanisms that can effectively manage these triggers and promote safe driving. Additionally, this study emphasizes the need to design interfaces that can evoke positive emotions and minimize negative ones, as a way of enhancing overall trust and safety in human-vehicle interactions. Further research in this direction can help to better understand the complex interplay between emotions, triggers, and driving behavior, and lead to the development of effective and safer human-vehicle interfaces.

How emotions like sadness and anger relate to triggers: However, the author [16] conducted an experiment with 61 drivers under three different road conditions. As depicted in 5, the experiments included Lane Keeping, Traffic Rules, Risky Driving, and Collision scenarios. As shown in Figure 5, both sadness and anger led to more errors than a neutral emotional state, regardless of the type of error. Furthermore, the sad condition led to more errors than the angry condition. Furthermore as shown in FIgure 6, [17] al also found that anger and sadness resulted in longer driving times than a neutral emotional state. As shown in Fig 6 the results revealed that anger and sadness led to significantly longer driving times to reach the same distance compared to a neutral emotional state.

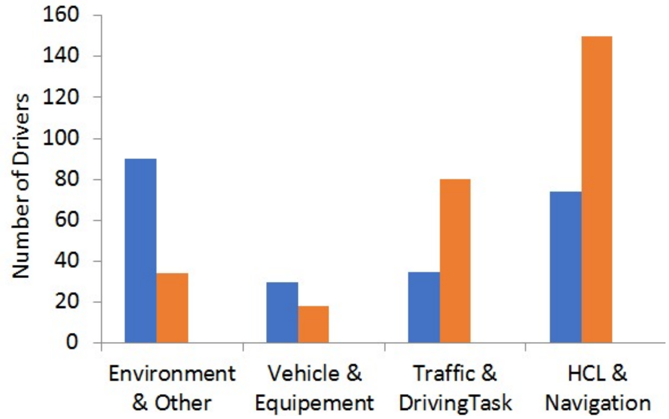

Fig. 4. **Trigger rate wrt to diffferent settings.** We observe forr both environment and vehicle-equipemen setting, the positive triggers denoted in blue outweighs the negative trigger denoted in orange. In contrast, the negative trigger dominate in the traffic and navigation-related setting

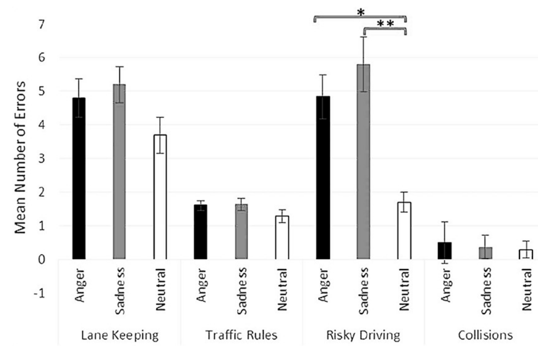

Fig. 5. **Error rate wrt four diffferent settings. We observe across the board both the negative emotions anger and sadness increases the error rate above the baseline neutral position. This shows the influence of negative emotions and necessity to improve better interfaces to mitigate the error rate.**

These findings suggest that negative emotions like sadness and anger have a significant impact on driving performance and lead to more errors and longer driving times. This highlights the importance of considering emotional states in human-vehicle interfaces and finding ways to mitigate the negative effects of such emotions on driving performance. Additionally, the results of these experiments demonstrate the importance of creating an interface that not only helps to improve driving performance but also helps to regulate and manage the emotional states of drivers while they are operating the vehicle.

How emotions like audio-based musicrelate to triggers: The [11] author conducted an experiments with 40 drivers for 20 minutes. They observed number of accidents reduced for happy drivers energetic voice and subdued voice of upset drivers. In Figure 7, we can observe that anger scores dramatically decrease after the audio-based feedback as scan be observed in the right side part of figure. The authors suggest that further research is required to determine the long-term effects of audio-based music on human emotions

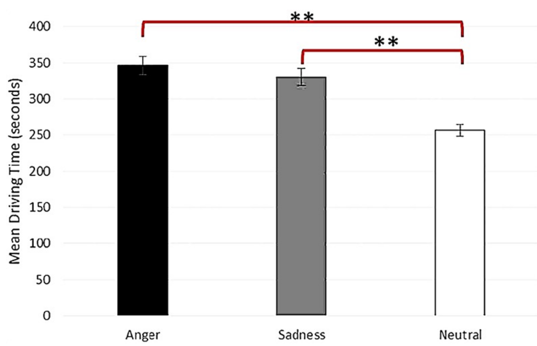

Fig. 6. **Impact of sad-emotion to driving time**. In the right figure, we plot the driving time for neutral position which is less than when the driver carries the negative emotion of sadness and anger

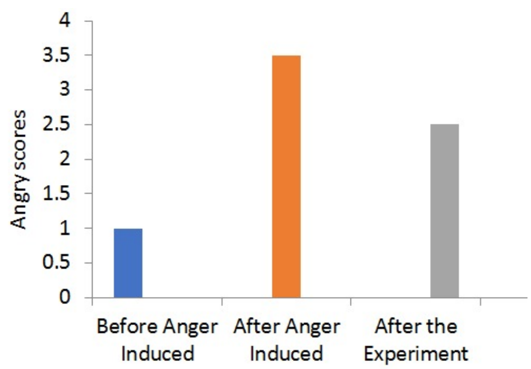

Fig. 7. **Impact of audio-based music feedback in regulating the anger.** In the left datapoint, we compute the angry scores as a basline and in the center datapoint, the anger score increase with angry induction and finally, in the right side, we can understand that the angry score decreases with audio-based feedback in the form of music.

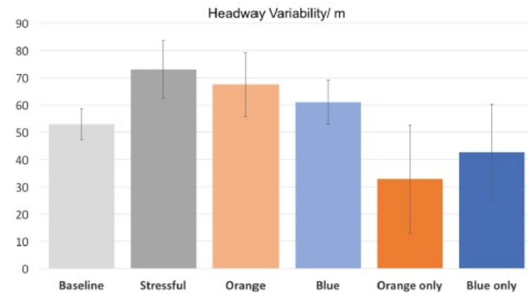

Fig. 8. Results from the driving performance analysis. The mean and SD of headway variability (left) for each of the rides. The two right most bars show lower values during the segments with the orange or blue lights on.

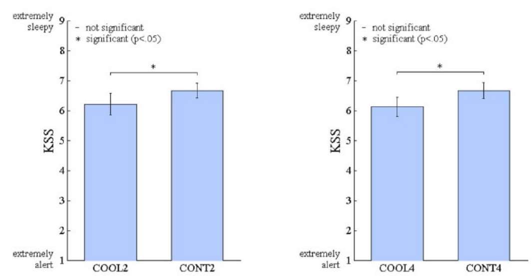

Fig. 9. Means and standard error of the average KSS (Karolinska Sleepiness Scale) ratings. In the left side, we comapre directly the COOL2 (2 mins of facial cooling) and CONT2 (Control-setup no cooling) and in the right COOL4 (4 mins of facial cooling) and CONT4 (no cooling). Both the settings, we find the find the sleepy metric is much lower in COOL setting than CONT setting.

and behavior in the context of driving.

In addition to the findings from the experiment mentioned above, it is also noted that audio-based feedback can significantly affect driver behavior and emotions. The use of music in particular can be an effective tool in reducing stress and increasing overall well-being while driving. This is important as stress and negative emotions have been shown to have a direct impact on driver performance, leading to decreased reaction times and an increased likelihood of accidents. By incorporating audio-based feedback in the form of music, it is possible to mitigate the negative effects of stress and improve driver safety. These findings demonstrate the importance of considering the emotional and psychological factors in human-vehicle interactions and highlights the potential of audio-based feedback as a means to enhance trust and safety in autonomous systems.

How emotions can be identified using light and futher regulate them: In another study, the authors in [8] aimed to investigate the effect of light color on driver stress levels. They conducted an experiment with twelve participants and collected 480 ratings over a 6-minute period for each participant. The results showed that stressful drivers had higher heart rates compared to neutral drivers. Additionally, the results showed that blue lighting led to an average heart rate of 70.2 beats per minute (bpm), orange lighting resulted in an average heart rate of 71.4 bpm, and the condition without any lighting had the highest average heart rate of 71.8 bpm. The study also found that headway variability, which is influenced by the behavior of preceding traffic and measures how well a driver is following the car in front, was lowest when the orange light was used in stressful situations. These results suggest that light color can play a role in reducing driver stress and improving driving performance.

Additionally, the results also indicate that orange light may have an even more pronounced effect, as it is associated with the lowest headway variability and the highest average heart rate. These results are promising and suggest that lighting can play an important role in enhancing human-vehicle trust and safety. Further research is needed to explore the full potential of lighting in human-vehicle interfaces, as well as its impact on other aspects of driver behavior and experience.

How facial cooling by temperature control can control and regulate emotions : In the line of above research, the authors in cite [26] use temperature as an medium to study the Karolinska Sleepiness Scale, which measures the sleepyness in a human. In this setting, we study the most interesting takeaway from the paper. In Figure 9, we study the KSS with and without facial cooling denoted as COOL and CONT. In the left side, we present a 2 minute facial cooling and in right we study for 4 minute facial cooling. In both the settings, the COOL had lower KSS scores than CONT counterpart. In other words, facial cooling based feeddback can potentially make drivers less drousy and also thus reduce potential crashes. Moreover, the authors also found that facial cooling was more effective in reducing drowsiness in the afternoon compared to the morning. This indicates that the impact of facial cooling on reducing drowsiness is influenced by the circadian rhythm of individuals. The results of this study suggest that temperature-based interfaces, such as facial cooling, can play an important role in improving driver alertness and safety on the road. These findings highlight the importance of considering multiple inputs in the design of human-vehicle interfaces.

V. Conclusion

In this seminar paper, we conducted a review of the existing literature on human-car interfaces to gain a comprehensive understanding of the current state of the field. Our analysis reveals that the field has advanced in various directions and several interfaces such as light, music, temperature, etc. have been integrated into autonomous systems to mitigate unfortunate incidents. However, despite these advancements, there are still challenges that need to be addressed. For example, ensuring the compatibility and usability of these interfaces in different driving environments, ensuring that the technology does not distract the driver and cause further hazards, and addressing privacy and ethical concerns. Another challenge is to find a unified and comprehensive method for evaluating these interfaces and measuring their impact on trust and safety in human-vehicle interactions.

In conclusion, the field of human-car interfaces is still in its early stages, but has already shown great potential for improving the driving experience and promoting trust and safety. Nevertheless, more research is required to address the challenges and refine these interfaces. Our hope is that this paper will provide a useful overview of the current state of the field and inspire further work to advance the development of human-car interfaces.

VI. Future work

Based on the findings of this literature review, there is potential for further exploration in the field of human-car interfaces. Future work could include conducting experimental studies to validate the effectiveness of different interfaces, exploring additional interfaces for inclusion in autonomous systems, and examining the impact of these interfaces on different demographic groups. Additionally, further research could be done to determine the optimal combinations of interfaces for maximum safety and comfort. By continuing to advance the field of human-car interfaces, it is possible to improve the overall driving experience and reduce the risk of accidents.

Futhermore, I believe few of below potential future research directions in the field of detecting emotions and leveraging them for improving safety in vehicles:

- **Multimodal Emotion Detection:** Combining multiple modalities such as facial expressions, body gestures, speech, and physiological signals to enhance the accuracy of emotion detection.
- **Personalized Emotion Detection:** Developing a system that can adapt to individual differences in emotional expressions and recognize emotions more accurately.
- **Driver State Monitoring:** Incorporating physiological signals such as heart rate, electrodermal activity, and body temperature to monitor the overall state of the driver and predict their emotional state.
- **Emotion-Aware Vehicle Control:** Implementing a control system that can dynamically adjust vehicle parameters based on the detected emotional state of the driver.
- **Integrating Emotion Detection with Driver Assistance Systems:** Improving the performance of driver assistance systems by considering the emotional state of the driver, e.g., alerting the driver in case of drowsy or stressed driving.
- **Cross-Cultural Emotion Detection:** Improving the robustness of emotion detection systems in the presence of cultural differences in emotional expressions.
- **Emotion-Aware In-Vehicle Interaction:** Designing in-vehicle interfaces that can respond to the emotional state of the driver and provide a more comfortable and safe driving experience.

These are a few potential future research directions in this field, and there may be many more opportunities to explore.

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