Multimodal Advanced Driver Assistance Systems: An Overview

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ABSTRACT

The development of new electronic devices for in-car usage has provided new challenges for automotive designers and engineers. Several researches have been focusing the ways drivers interact with the vehicle, seeking to understand the influence of the modern technological devices on the errors committed by the drivers. Although the electronic devices may lead to driver inattention, technological aid can improve drivability and safety by means of providing to the driver helpful information about the vehicle status, especially during unexpected and urgent situations. ADAS - Advanced Driver Assistance Systems, in such context, play the role of providing helpful features to the driver. Due to the high visual demand of the driving task, other human processing channels may be used for driver-vehicle communication. This work presents and discusses some advanced driver assistance systems proposed by the scientific community that take advantage of multimodal human processing to better safety and drivability.

Author Keywords

Multimodality, warning design, driver vehicle interaction, advanced driver assistance system

ACM Classification Keywords

H.5.2 User Interfaces

The new in-vehicle entertainment and communication devices result in a loss of attention and in a delay in the driver's reaction when it is required. The usage of multimodal warning systems in these cases is believed to bring faster reaction times when the driver is requested to resume control. Lane departure assistance, sound alerts and collision avoidance systems are possible applications of the multimodal warning systems.

The idea of using new ways of interaction to help drivers in the task of lane keeping is under study of several researches [4,5,9,10,15,17,18]. Additionally, researches about the usage of sound alerts in the automotive interior space [1,3,4,7,12,13,15,17,20] found out that the exploitation of the auditory channels could improve drivability especially in low visibility conditions and that its spatiality is really able to indicate the location of the sound source.

Driver assistance systems could help drivers not only with lane keeping task but also in collision avoidance with other vehicles. One of the most frequent causes of road accidents is the occlusion of threats from the driver visual field. The rear mirrors give the driver a visual feedback of a certain area at the back, but there is still a blind zone, where another vehicle (e.g. a motorcycle) cannot be detected.

In the case of imminent collision detection, the reaction time of the driver should be even shorter than in the case of an unexpected lane departure. Studies such as [15,17] have discussed if warning sounds only calls the driver's attention, letting the visual sense alone to recognize the appropriate action to be taken or if the auditory perception itself guides an action.

Riener [14] suggests that the usage of the haptic sensory channel could represent a great improvement in the effectiveness of the Advanced Driver Assistance Systems, since the vibro-tactile feedback can be highly significant when it is needed to attract the driver's attention, what consequently reduces reaction times.

The combined usage of visual, auditory and haptic sensory channels for driver assistance systems is the theme of this article. In the next sections, an overview of a series of studies on multimodal driver assistance system is presented, followed by a discussion over the common aspects of the different cited approaches.

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MULTIMODAL DRIVER ASSISTANCE SYSTEMS

Definition and architecture

In [21], Zheng proposes an architecture for a driver assistance and safety warning system in three layers, combining information from the vehicle and road sensors into a real-timing decision making system to interact to the driver using video, display, audio and remote control interfaces.

Zheng emphasizes three major functions of a driver assistance and safety warning system: i) provide just-in-time information about the vehicle, road and surroundings; ii) Warn the driver passively when his or her vehicle is in a hazardous situation and iii) Warn the driver proactively about possible hazardous situations on the basis of the vehicle's current position, orientation and speed, and the road conditions or surrounding environment, taking control of the vehicle.

Adell et al. [1] specifies that in a warning system, visual alarm must be used when there is time to react and auditory stimuli are better when an action is required immediately. Aiming to provide recommendations for HMI solutions for a driver assistance system to keep a safe speed and distance, Adell et al. conducted a driving simulation study to compare a number of visual, auditory and haptic systems.

Based on several qualitative evaluations, they concluded that for speed limit keeping, the best visual information consists of a speed limit traffic sign icon indicating the legal speed limit close to the dial scale where the corresponding value is marked. The auditory warning for a too short distance should be a speech message 'distance' and for haptic speed and distance warning, a pulsating force-feedback pedal is recommended.

In [10], Jordan, Franck and Michel classify the driving assistance devices in four categories: i) perception; ii) mutual control; iii) delegation and iv) full automation from passive to active. For the mutual control cooperation mode, driver is warned if the assistance device identifies discrepancy between the decision taken by the driver and the decisions the device would take.

Jordan, Franck and Michel measured the duration of lateral deviation in a simulator experiment and concluded that asymmetrical triangular oscillations on the steering wheel associated to auditory warnings resulted in better lane keeping results than only auditory warning, only symmetrical vibratory warning and an association of these latest two.

Haptic interfaces

Riener and Ferscha state in [14] that approximately 80% of all human sensory input is received via the eyes and another 15% via the ears, what favors haptic display usage for vehicle-driver notification, which is actually proposed in their work by integrating vibro-tactile elements in the driver's seat and back.

Experiments were conducted by Riener and Ferscha [14] to evaluate the usage of vibration stimulus to alert the driver to turn right and left and to turn light on and off. They compared reaction time for auditory, visual and haptic stimuli and concluded that haptic feedback is eligible to support interaction based on vision or sound.

Two experiments were performed in [8] to evaluate the efficacy in keeping longitudinal control using a vibration feedback on driver's back on the seat or front on the belt to indicate whether a car is approaching from behind or the vehicle is too close to the forwarding car, respectively.

In the first experiment, subjects were asked to brake or accelerate after a vibration stimulus according to the scene identified on the projection upfront and on the view of the rear mirrors. Ho, Tan and Spence [8] discovered that participants responded more rapidly to critical visual driving events preceded by a valid vibrotactile cue from the same direction than when preceded by an invalid cue from the opposite direction.

Fletcher et al. state in [6] that driver assistance systems must be intuitive, by making sense immediately, nonintrusive, it means, shall not distract or disrupt the driver and overridable, letting to the driver autonomy to resume control.

They suggest that force-feedback and auditory signals as new interfacing systems can be useful for driver assistance system such lane tracking, obstacle detection, blind-spot monitoring and road-sign detection.

As stated in [7], the United States Army has focused on reducing operator workload and enhancing situation awareness and soldier performance in their human robotic interface by using multimodal displays. Haas [7] states also that audio and tactile displays are effective for simple, short messages that do not need to be referred to later.

Auditory interfaces

Studies on auditory warnings are widely being performed by the scientific community. Leung et al. discuss in [13] the human ability to perceive meaning of different sound interface styles. They discovered that speech warnings and auditory icons, which reproduces a natural sound, were equally good understood, learnt and retained by the subjects, while abstract sounds, such as simple tones, presented a worse performance.

On the other hand, Langlois et al. [12] found out that urgency perception is better understood across different countries for abstract sound than for environmental sounds. Their results show that auditory warnings are perceived as urgent when the frequency is high. Short cadence period and short attack time also increase urgency perception.

Preparation and Compatibility Principles

Rossmeier, Grabsch and Döring [15] identified that directional auditory feedback on a lane departure warning system not only calls the driver to attention, letting to the visual perception the decision on how steering reaction must be executed, but also influence human reaction times. By performing some experiments with asleep drivers in a driving simulator, they showed that steering reaction in some cases was too fast to be initiated by the visual impression of the driver scene alone, concluding, then, that the auditory stimulus impacted the reaction time.

Additionally, Navarro, Franck and Hoc [9] found out that the usage of directional steering wheel vibration resulted in better reaction times when compared to lateralized auditory warning or non-directional steering wheel vibration. But, in this case, the usage of multimodal information, adding an auditory warning to the direction haptic feedback did not improved driver performance. They concluded that the benefits of the motor priming haptic interface resulted in a faster reaction time than the auditory one and is good enough for a lateral control assistance system.

By the other side, Bellotti et al. [3] show that 3D sound messages can convey information regarding orientation, position and distance, reducing eyes-off-the-road time. However, they stress that several issues need to be considered for 3D sound usage inside the vehicle. For instance, some personalization and adaptation phase must take place to comply the different driver preferences and specificities.

The combined usage of haptic and auditory feedback for spatial localization is explored by Bertoldi and Filgueiras [4] and Fitch et al. [5]. Bertoldi and Filgueiras focused on the reaction time reduction resultant of the natural mapping of the directional auditory warning provided by loud-speakers placed close to the driver's head and by the vibratory elements placed on the driver's seat. Fitch et al. focused on the localization accuracy of the threat direction and the result show that adding haptic feedback to the auditory alarm increased the percentage correct localization from 32% to 84%.

DISCUSSION

The goal of the driving task is to keep the car's position and speed under control and avoid collisions with other vehicles until a specified destination is reached. The several studies presented above may contribute to the development of driver assistance systems, which can provide a safer driving task.

According to Wickens and Hollands [19], the determinant variables for the reaction time in the selection of an action are stimulus modality, intensity, expectation, preparation and compatibility between stimulus and action. These parameters should be considered in every proposal for a driver warning system, since the time to react in the situation where such system is requested is typically very short.

Stimulus modality is a main point in all presented works. They explored the usage of auditory, haptic and visual perception channels in creative ways to provide to the scientific community knowledge about how the human performs when submitted to such stimuli.

Some studies [8,18] focused on the haptic interaction to transmit information to the driver, such as turn commands and longitudinal controls to brake and accelerate. Both studies concluded that haptic interaction may be suitable for in-vehicle usage, but they also warn that additional studies are necessary to lead with confusion and annoyance.

Other works [11,12,13,15] studied the characteristics of sound interface that improves understandability, urgency perception and reaction time. The development of an auditory driver warning may be highly influenced by their discoveries, since the usage of the auditory channels to convey information can relieve the visual perception channel and reduce eyes-off-the-road time.

Intensity, expectation and preparation are considered in [1,8,10,11,15]. The selection of a pulsating pedal force-feedback intensity pattern in [1] resulted in a better speed and distance control. Expectation was the explanation of Wiese and Lee in [11] to justify the improved reaction when the e-mail alert was played 1000ms before the collision warning instead of close before it (300ms). The lane departure system proposed in [15] takes advantage of the preparation that the sound warning implies to the asleep driver, in order to faster its reaction time when he opens his eyes.

Compatibility between stimulus and action are the topics of [4,5,6,10] studies. In [4,5] the directional seat vibration and auditory feedback indicates to the driver the direction of a threat, which allows the correction steering and braking reaction. In [10], asymmetrical triangular oscillations on the steering wheel provide the driver the suggested action to be taken in the proposed mutual control system.

CONCLUSION

Multimodal driver assistance systems are an exciting field of research. Besides the great results achieved by the works presented here, many of them agree in the point that there is still a lot be done. Auditory, haptic and visual perception channels may be combined in innovative ways, considering intensity, expectation, preparation and compatibility between stimulus and action to provide a safer driving.

The usage of multimodality in driver assistance systems shortens reaction times, reduces eyes-off-the-road time, improves driver situation awareness and increases safety while driving.

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