Real-Time Monitoring of Driver Distraction: State-of-the-art and Future Insights

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1. Introduction

Approximately, 1.25 million people die every year on roads worldwide, with millions more sustaining serious injuries and living with long-term adverse health consequences [1]. Globally, road crashes consist one of the leading causes of death, especially among young people, as well as the number one cause of death among those aged 15–29 years [2].

To date, several human factors have been identified, which affect the likelihood of a road traffic crash or a serious injury, but among them, driver distraction and inattention are some of the major contributors demonstrating the increased risk of road traffic fatalities and injuries [3]. In particular, driver distraction (in-vehicle or external) represents an important factor of driver state with negative impact on road safety and is a major cause of vehicle crashes worldwide with an increasing importance [4]. At the same time, technological developments make massive and detailed operator performance data easily available, via new in-vehicle sensors that capture detailed driving style. This creates new opportunities for the detection and design of customized interventions to mitigate the risks, increase awareness and upgrade driver performance, constantly and dynamically [5].

The optimal exploitation of these opportunities is the challenge that i-DREAMS faces. The overall objective of the European H2020 i-DREAMS[2] project is to define, develop, test and validate a context-aware safety envelope for driving in a 'Safety Tolerance Zone' (STZ), with a smart Driver, Vehicle & Environment Assessment and Monitoring System.

Within, the above framework, the aim of the current research is to review and assess state-of-the-art in-vehicle approaches and technologies as well as the various driver recording tools to monitor the driver's distraction and inattention. To achieve this objective, a comprehensive literature search (scientific as well as grey literature) was conducted. Identified measurement methods and associated technologies were assessed based on pre-defined criteria such as intrusiveness and effectiveness among others. The review was conducted from a transportation mode perspective, beginning with car technologies which were covered most extensively in literature.

The paper is structured as follows. In the beginning, the overall objective of the i-DREAMS project as well as the aim of this research is provided. Subsequently, the theoretical background of driver distraction definition and corresponding indicators is given. This is followed by a section, in which, the methodological approach of the current research is presented. An extended literature review is carried out regarding all available state-of-the-art technologies of assessing driver distraction. In the next step, the results of technologies and systems that has been identified for the real-time monitoring of driver inattention are presented. Finally, overall conclusions for the continuous monitoring of driver distraction are highlighted in order to assist researchers and practitioners.

2. Background

Driver distraction can be defined as "a diversion of attention from driving, because the driver is temporarily focusing on another event, task, object or person which is not related to driving" [4]. As a result, the driver's awareness, decision making ability as well as driving performance are reduced, leading to an increased risk of corrective actions, near-crashes or crashes. Following the definition above, the current study focuses on identifying the ways in which distraction and inattention can be monitored during trips and less attention is given to the relationship between driver distraction and road safety. For instance, Papantoniou et al. [3] provided two very interesting approaches with a review of driving performance parameters critical for distracted driving with regards to road safety [6].

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[2] Further general project information can be found on the website: https://idreamsproject.eu

As real-time measurement of physiological and behavioural indicators is crucial (especially for the i-DREAMS concept), the most important indicators for distraction will be introduced below with definitions and descriptions. In general, physiological measures are devoted primarily to continuous measurement of the physical responses of the body, for example, heart rate or heart rate variability. The most reliable and sensitive physiological measures include eye movements, such as eye blink rate, blink duration, fixations, saccades and interval of closure as well as head movements, such as rotation and orientation. A range of driver distraction measures, as well as their indicators that have been used to evaluate the impact of distraction on driving performance is provided in Table 1, including behavioural and physiological measurements.

Table 1: A range of driver distraction measures with their indicators

Driver distraction measures	Indicators
Longitudinal control [7]	speed, headway
Lateral control [8]	lateral position, steering wheel control, standard deviation of steering wheel angle
Reaction time [9]	perception response time (PRT), brake response time (BRT), time-to-collision (TTC)
Gap acceptance [10]	number of collisions, gaps accepted
Eye movements [11]	glances, saccades, fixations, blinks, gaze direction, eyes-off-road-time, electrooculography (EOG), percentage of eyelid closure time (PERCLOS), percentage of time spent not looking ahead (PERLOOK)
Head movements [12]	rotation, orientation, pose

3. Methodology

In order to review and assess the state-of-the-art attention and distraction measurement techniques, a systematic search of relevant scientific and grey literature was carried out. Although there was a range of studies investigating the impact of attention and distraction in the context of road safety, this literature search and review explicitly focused on research relating to objectively measuring and detecting driver distraction and inattention during trips, preferably in real-time driving conditions. The key terms were then entered into the databases, with the following inclusion criteria:

- Published between 2000-2022
- Search term included in title, abstract or key words
- Language as English
- Document type as journal or review
- Source type journals

The search was conducted in the databases ScienceDirect, ResearchGate, Scopus, PubMed and Google Scholar. Publications were deduplicated, screened by title (624 publications) and then by abstract. Relevant literature was documented and summarized. The limitation was set to publications after 2000 and only publications from peer-reviewed English language journals were considered for inclusion. Eventually, 29 publications were screened thoroughly. The literature predominantly concerned car driving, however, the extent of the transferability of the findings to the other i-DREAMS modes (i.e. truck, bus, train and tram), was discussed.

4. Results

The results of the literature review revealed a variety of different sensors and systems that have been selected to detect driver distraction. The most prominent technologies that were applied, not only in the academic field, but also in commercially applications. The research literature documents two types of measures associated with periods of distraction or inattention: physiological and behavioural indicators.

4.1. Physiological indicators

In the past few years, many researchers have been working on the development of safety monitoring technologies using different techniques. To begin with, Toyota and Lexus' Driver Attention Monitor have been conceived to detect driver attentiveness, using infrared sensors and cameras monitoring the driver's face [13]. This technology is able to identify the driver's face orientation and facial expressions. With regards to the latter, previous works on detecting driver behaviour proved that facial movements provide useful information associated with secondary tasks, such as talking [14]. In particular, features related to brow motion and eye lids movements can be used to capture signaling cognitive load [15]. Moreover, the system found to be non-intrusive solution for real-time distraction monitoring, providing flashing lights and warning sounds. If no action is taken, the vehicle applies the brakes (a warning alarm sounds followed by a brief automatic application of the braking system). Fernández et al. [16] proposed the EyeAlert system as an ideal technology which focuses entirely on the driver's alertness levels or distraction from the road ahead. When the infrared camera or sensors monitor driver's eye closure rate, or blink duration and unsafe patterns are identified, an audible alarm is sounded. According to the available product information, the portable device focuses on the driver's inattention to the road ahead and it was revealed to be an effective technology which works regardless of weather or roadway conditions such as fog, snow or rain.

Delphi Electronics, developed a real-time vision-based camera Driver Status Monitor [17]. By detecting drivers' facial characteristics, this technology analyzed eye-closures and head pose in order to infer their distraction and inattention. In addition, the system found to be an effective and non-intrusive solution which provided real-time warnings and notifications and prevent drivers from being too distracted with non-driving tasks. Seeing Machines is an effective and non-intrusive face and eye-tracking system, monitoring the movements of a person's eyes, face, head, or facial expressions and distraction events in real-time through in-cab sensors and cameras [18].

Similarly, Smart Eye is an eye-tracking system measuring eye fixation pattern, smooth pursuit of eye movement, blink rate and eye lid control through cameras on dashboard [19]. An interesting survey conducted by Kumar et al. [20] revealed that Smart Eye device is a user friendly, cost-effective and easily accessible oculomotor monitoring tool and it did not appear to be an intrusive solution. Cardio Wheel, an Advanced Driver Assistance System found to be an effective and unintrusive solution that acquired the electrocardiogram (ECG) from the driver's hands via sensors on the steering wheel to continuously detect distraction [21]. One of the most important advantages of this technology is that it can be integrated with certain third-party systems, such as Mobileye and GeoTab, providing complete fleet management solutions for enhanced road safety.

Furthermore, Texas Instruments Biometric Steering Wheel is a non-intrusive technology for measuring driver distraction but no information was found about the validity of this technology [22]. Texas Instruments proved a concept of how biometric sensors mounted on a steering wheel can be used to obtain important information from a driver in real-time, on condition that simple hand contact is required [23]. This product combines modern solid-state technology with low-power processing ability and wireless communication to detect respiration rate, pulse rate as well as ECG-based heart rate from a standalone system. According to the available technology information, it was found that it cannot be used in real-time conditions and it is not available for sale. However, it can be only available for testing in a simulator environment.

In addition, Empatica E4 Wristband is a wearable device, equipped with sensors that offers real-time high-quality physiological data [24]. It was found to be an effective, easy to use and non-intrusive technology for the identification of driver distraction. The system's battery runs 48 hours and an internal memory allows to record for up to 60 hours of data. Lastly, hand sensors, such as a hand magnetic rings or eyeglasses clips were less frequent approaches in order to monitor driver distraction [12]. Tobi eye-tracking glasses are less effective for monitoring driver distraction as the calibration of eye tracker might be time-consuming [25]. Eye-tracking glasses are intrusive as drivers are required to wear them during driving. Results indicated that this technology was not suitable for on-road trials.

4.2. Behavioural indicators

Mobileye solution is a forward facing camera, which alerts drivers when an imminent rear-end collision is looming, helps to keep a safe following distance, warns then about unintentional lane departures, and provides indications about the detected speed limit signs. It was found to be an effective and non-intrusive solution for monitoring the adverse consequences of driver distraction, promoting road safety. Moreover, it should be noted that smartphones, with their embedded sensors, such as gyroscopes, accelerometers and magnetometers, were found to be promising tools for monitoring driving behaviour effects of distraction [26]. Smartphone applications which can provide measures such as lateral and longitudinal acceleration, can be utilized for surrogate safety measures capturing observed distraction and inattention. For instance, You et al. [27] presented a driver safety application, called CarSafe, which detects drivers to dangerous driving conditions as well as inattentive driving and alters the drivers accordingly.

It should be mentioned that since smartphones are portable devices, they are more related to the person who carries them, than to the car. This implies that these devices are not directly linked to the car structure, well-fitting many vehicle types. Smartphone solutions are increasing in vehicle telematics because they are scalable, upgradable and low cost. Also, they can provide instantaneous driver feedback and have many embedded sensors. Issues that have to be considered are the low quality of the sensors, which are not primarily selected for vehicular measurements. Moreover, smartphones are not fixed, leading to issues as regarding relative orientation, driver/passenger recognition and GNSS coverage.

5. Discussion

In order to monitor driver distraction and inattention, several hardware and software systems and technologies were examined. One of the main conclusions that can be drawn is that the most frequently utilized method for the continuous driver monitoring found to be the use of physiological indicators. Eye movements such as the number and duration of eye fixations as well as ECG measures and head movements are indicated to be the most reliable ones. It is worth mentioning that the majority of the studies reviewed, were conducted and tested mostly in driving simulated environments with limited studies using open field driving experiments with real road conditions within a specific transport mode. This result is plausible due to the danger of testing inattention on road driving environments, given the ethical constraints that come with inducing distraction. Also, a manipulation check is easier to conduct in the controlled environment of a simulator. However, the results obtained in a driving simulator study may be applied to a real traffic environment. In addition, in driving simulators, there was not found a particular technology, device or navigation system which was directly connected into the vehicle for distraction monitoring. For instance, no product was able to discriminate between cars' or trains' interior. Consequently, all methods that were developed from driving simulator experiments in order to measure distraction and inattention, were easily transferable to different transport modes.

Regardless of the measurement methods and their quality, practical considerations for implementations in i-DREAMS should be noted. The vast majority of reviewed literature and information concerned car driving. An assessment was conducted to see to what extent the conclusions were transferable to other modes. It was revealed that most of methods, technological devices and systems mentioned above, which measure driver distraction or attention, can be easily transferred to all transport modes and no indication was found that contradict the assumption that the identified methods can be transferred from the context car to the other i-DREAMS modes: trucks, buses, trains and trams.

Wearable devices, such as eye tracking glasses were found to work only with the assistance of project staff in a simulator study and they were not available for on-road testing. It should be clearly mentioned that the impact on the naturalistic driving character has to be considered when asking the participants to wear a device whenever they drive. For instance, when using cameras facing the participant, GDPR is to be considered carefully. Hence, with the exception of wearables, it can be concluded that attention monitoring systems are easily transferrable to all four modes of i-DREAMS. This could be very important for the project, providing flexibility, meaning that the system does not need to be redesigned for each mode of transport.

6. Conclusions

The objective of this study was to review and assess state-of-the-art technologies and systems to monitor driver distraction and inattention. In addition, a selection of driver inattention factors including measurement methods were summarized and driver distraction indicators were reviewed.

Technologies and equipment used in the reviewed studies measuring inattention and distraction were separately reviewed and assessed in terms of intrusiveness and effectiveness and overall applicability for the i-DREAMS project purposes. An assessment of available technology was provided, focusing on the theoretical suitability of single devices or technologies for measuring the driver state constructs in question and the applicability in two settings 'simulator' and 'on-road trial'. Intrusiveness was the main reason for a negative assessment of a device for the on-road setting as well as prioritization of positive assessed devices was made in terms of effectiveness.

Systems aimed at increasing driver safety to be effective, an as accurate as possible risk monitoring instrument is required. Moreover, impact on driver safety can be expected to be higher, if proposed technologies in some way combine the local perspective (i.e. in-vehicle assistance with instant impact on driving) with the general perspective (i.e. longer-term support for a gradual change process in the vehicle operator). The development, implementation and testing of the best and most suitable technological solution (i.e. within the i-DREAMS platform) could bring together these functionalities.

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