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

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Abstract

Human-related factors, especially driver distraction and inattention, are major contributors to a large number of serious road crashes. It is evident that distraction reduces to a great extent driver perception levels as well as decision making capability, which negatively affects driver's ability to control the vehicle. An effective way to reduce these kinds of crashes would be through monitoring drivers' mental state or driving behaviour and alerting them when they are in a distracted state. In recent years, several inexpensive and effective detection systems have been developed in order to mitigate driver inattention. This study aims to critically review and assess the state-of-the-art in driver attention measuring, as well as the corresponding technologies for risk assessment and mitigation, as part of the i-DREAMS project. A thorough literature review was carried out in order to compare and contrast technologies that can be used to detect, monitor or measure driver's distraction or attention. In most of the identified studies, driver distraction was measured with respect to its impact to driver behaviour. Real-time eye tracking systems, cardiac sensors on steering wheels, smartphone applications and cameras were found to be the most frequent devices to monitor and detect driver distraction. On the other hand, less frequent and effective approaches included electrodes, hand magnetic rings and glasses.

Keywords: Distraction, Attention, State-of-the-art Technology, Inattention Monitoring System, Driver State Monitoring.

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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 are 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]. Currently, road crashes are estimated to be the ninth leading cause of death across all age groups, and are also predicted to become the seventh dominant cause of death by 2030 [1].

Several human factors have been identified which affect the likelihood of a road traffic crash or a serious injury, but among them, driver distraction or inattention are some of the major contributors demonstrating the increased risk of road traffic fatalities and injuries [3, 4]. It is worth mentioning that limiting the exposure to these risk indicators is essential and critical to the success of efforts in order to reduce traffic injuries and therefore promote road safety.

Specifically, 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 [5]. 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 [6]. 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. Taking into account, on the one hand, driver background factors and real-time risk indicators, and on the other hand, driving task complexity indicators, a continuous real-time assessment will be created to monitor and determine if a driver is within acceptable boundaries of safe operation (i.e. STZ). Testing and validation will be applied to car, bus and truck drivers as well as to tram and train drivers.

Within, the above framework, the aim of the work documented in this paper 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. Following this, the transferability of the results to another modes (i.e. buses, trucks and trains/trams) was assessed and if necessary, a dedicated further search for a certain mode was carried out.

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, several definitions with regards to the terms of driver distraction and inattention are presented and the types of driver distraction are also analyzed. Moreover, the methodological approach of the current research is presented. An extended literature review was 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. Defining distraction and corresponding indicators

The use of different, and sometimes inconsistent, definitions of driver distraction can create a number of problems for researchers and road safety stakeholders. Definitions currently utilized in the literature are either from relevant scientific studies, or official bodies and organisations. For example, the International Standards Organisation (ISO) defines driver distraction as being "attention given to a non-driving related activity, typically to the detriment of driving performance" [7]. In addition, Young et al. [8] considered that distraction is defined as "the presence of an event, activity, object or person within or outside the vehicle which compelled or tended to induce the driver's

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

shifting attention away from the driving task", while Stevens and Minton [9] proposed driver distraction as "physical events, actions or conditions, in or on the vehicle that divert attention from driving". According to Streff [10], distraction involves "a shift in attention away from stimuli critical to safe driving toward stimuli that are not related to safe driving" and Regan and Strayer [11] claimed that distraction can be defined as "a diversion of attention away from activities critical for safe driving toward a competing activity".

As there is not a consistent definition for driver distraction and driver inattention across studies, the comparison among them, may be difficult or sometimes impossible. Even seemingly, similar works sometimes investigate slightly different concepts or measure different outcomes. It is worth mentioning that inconsistent definitions may also lead to disparate results of road crash data and therefore, to contrasting estimates or assumptions of the role of distraction in road accidents. Consequently, these concerns highlight the need to develop a common, generally well-accepted definition of driver distraction.

For that purpose, 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" [5]. 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. [4] provided two very interesting approaches with a review of driving performance parameters critical for distracted driving with regards to road safety [12].

As real-time measurement of physiological and behavioural indicators is crucial (especially for the i-DREAMS concept), the most important indicators 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 (i.e. longitudinal control, lateral control, reaction time, gap acceptance), as well as physiological measurements (i.e. eye and head movements).

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

Driver distraction measures	Indicators
Longitudinal control [13, 14]	speed, headway
Lateral control [15, 16]	lateral position, steering wheel control, standard deviation of steering wheel angle
Reaction time [17, 18]	perception response time (PRT), brake response time (BRT), time-to-collision (TTC)
Gap acceptance [19]	number of collisions, gaps accepted
Eye movements [20-22]	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 [23-26]	rotation, orientation, pose

Driver distraction is a multidimensional phenomenon and there is not a unique driving performance measure which is able to capture all effects of distraction. The large number of driver distraction measurements, presented in Table 1, indicates that the decision regarding which measure or set of measures is used should be guided by the specific research question [5]. In addition, visual distraction has a greater effect on lateral control measures, whereas cognitive distraction effects more visual scanning behaviour. Among all trackable parameters, longitudinal and lateral control measurements, surrogate safety measures such as reaction time or gap acceptance, and eye or head measures are deemed to be the most crucial to identify driver distraction. However, the diversity in the measures used, in combination with the diversity in the design of the experiments (i.e. road and traffic factors), often complicated the synthesis of the results, especially for less commonly examined distraction factors.

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 2000-2020
- 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. Additional key references were also added. 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 commercially applications, were driver facing cameras (Delphi Electronics, Optalert, Mobileye), eye tracker systems (EyeAlert, SensoMotoric Instruments, Seeing Machines, Smart Eye, Phasya) or glasses (Tobi eye-tracking glasses), smartphone applications (CarSafe), wearable devices (BioRadio, FlexComp, Shimmer 3, Empatica E4 Wristband) and steering angle sensors (Cardio Wheel, Texas Instruments Biometric Steering Wheel). 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 [27]. 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 [28]. In particular, features related to brow motion and eye lids movements can be used to capture signaling cognitive load [29]. 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. [30] 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 [31]. 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. Furthermore, SensoMotoric Instruments (SMI) provided an eye-tracking system which measured gaze direction, head pose and orientation, PERCLOS, eyelid closure and blink, as well as pupil diameter and position [32]. It was revealed that SMI's InSight computer-based system was an effective way to monitor driver distraction, however user calibration was necessary. Furthermore, 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 [33].

In the same way, 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 [34]. An exit survey was conducted by Kumar et al. [35] 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. As all of the participants claimed that they did not face any difficulty in understanding the visual pursuit task, it was an effective technology for detecting driver inattention. In addition, the early warning distraction technology of Optalert, was found to be a non-intrusive solution, as drivers did not need to wear or do anything [36]. The product is designed to detect various signs, such as facial features, changes in the pattern of eye and head movements and skin conductance. A very interesting finding by Corbett [37] revealed that drivers indicated that Optalert would be the preferred and effective option as a research tool related to distraction. Results also confirmed that the system leads to improved safety and warns the drivers when their distraction exceeds predetermined levels through visual and audio alerts.

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 [38]. 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 [39]. 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 [40]. 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.

BioRadio by Great Lakes NeuroTechnologies is a wearable device that acquires physiological data for detecting driver distraction through electrodes attached to fingers [41]. It is easy to set up and operate and the wearable wireless physiology monitor can stream data to a computer via Bluetooth or save it to memory for mobile monitoring. Results indicated that the wireless connectivity and the way it records signals was seamless and noise-free. Furthermore, FlexComp from Thought Technology is a wearable device using electrodes attached to fingers [42]. Sensor locations can be set on non-intrusive locations on the body such as on forearm, as there are less intrusive than on fingers and less sensitive to movement. This technology is mainly used for biofeedback and the transferability to the driving context is not clear. As the above wearable devices are wireless, portable and easy to use technologies, they are a suitable solution for clinical research and teaching, but they can be utilized only with assistance of project staff in a simulator study and they are not appropriate for on-road tests.

In addition, Shimmer 3 provides a wearable device using wireless and robust body worn sensors [43]. Specifically, photoplethysmography (PPG) ear clip using electrodes position on chest or arms, while a GSR unit, EMG3 using electrodes attached to two fingers. Shimmer 3 is a good solution for a simulator study as there are non-invasive and low-cost sensors, suitable for in car use. However, results have to be further validated with a larger sample as there is was only small sample size examined. Furthermore, Empatica E4 Wristband is a wearable device, equipped with sensors that offers real-time high-quality physiological data [44]. 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. As a result, Empatica E4 is an ideal solution for longitudinal studies.

Hand sensors such as a hand magnetic rings or magnetic eyeglasses clips were found to be less frequent approaches in order to monitor driver distraction [24]. Tobi eye-tracking glasses are less effective for monitoring driver distraction as the calibration of eye tracker might be time-consuming [45]. 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 [46]. 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. [47] 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. Table 3 provides an overview of devices and technical equipment used in the reviewed studies on measuring distraction and inattention.

Table 3. Overview of devices and technical equipment used in the reviewed studies on measuring distraction and inattention

Product/ Technology	Equipment, measurement method	Intrusiveness	Simulator (Yes/No)	On Road Test (Yes/No)	Indicators	Overall assessment and considerations for i-DREAMS project
Seeing machines	In-cab sensor, cameras facing forward and driver	Contact free	Yes	Yes	Face and eye tracking indicators	+ Used in truck fleets + Planned to be used on UK rail network + Already implemented in trams following tram crash + Can be designed to issue alerts + Established product + Combine multiple camera sensors to detect a wider range of movements - Need installation and training on use/analysis - No clear results on time headway
Optalert	Video cameras on dashboard, steering wheel	Contact free	Yes	Yes	Vision based: eye tracking, facial features, amplitude and velocity ratio of blinks	+ Issues early warnings + Driver does not need to wear or do anything + Established product - Need installation and training on use/analysis - Licensable software
Cardio wheel	Sensors on steering wheel	Low	Yes	Yes	ECG, HRV	+ Dashboard for fleets of vehicles + Can be integrated with certain third-party systems + Non-intrusive - Requires contact of both hands to steering wheel - Requires custom steering wheel
Smart eye	Eye tracking cameras on dashboard	Contact free	Yes	Yes	Vision based: eye, face and head tracking	+ Developed for automotive industry + Established product + Non-intrusive + Driver does not need to wear or do anything - Need installation and training on use/analysis - Sensitivity of the system
Texas Instruments Biometric Steering Wheel	Sensors on steering wheel, measuring pulse, respiration	Low	Yes	Yes	ECG heart rate, pulse rate, respiration rate	+ Fully assembled board developed for testing and distraction validation + Non-intrusive - Requires contact of both hands to steering wheel - Unsure of validation - Not available for sale

Product/ Technology	Equipment, measurement method	Intrusiveness	Simulator (Yes/No)	On Road Test (Yes/No)	Indicators	Overall assessment and considerations for i-DREAMS project
BioRadio by Great Lakes NeuroTechnologies	Electrodes attached to finger (in study: placed on steering wheel)	Medium	Yes	No	ECD, EMG	+ Wireless connectivity + Seamless and noise-free recorded signals + Used for clinical research - Signals with accuracy of only 70% - Use only with assistance of project team
Empatica E4 Wristband	Wristband with sensors	Low	Yes	Yes	EDA sensor	+ Easy to use technology + Battery runs 48 hours + Internal memory with up to 60-hour recorded data + Additional equipment: 3-axis Accelometor to capture motion-based activity, event-mark button - No details on HR parameters provided
FlexComp from Thought Technology	Electrodes attached to fingers	Medium	Yes	No	HRV, EDA	+ Sensor locations can be set on non-intrusive locations on the body + High quality signals + Easy to use technology + Use fiber optic for real-time monitoring - Mainly used for biofeedback - Transferability to driving not clear - License restriction is enforced through limitations on the software's functionality
Shimmer 3, including PPG ear clip	Electrodes positioned on chest or arms	Medium	Yes	No	ECG	+ Electrodes are placed on participant fixed for each trial + Can be used with other devices - Used in laboratory research
Shimmer 3 GSR unit, EMG3	Electrodes attached to two fingers	Medium	Yes	No	EMG	+ Electrodes are placed on participant each trial + Non-invasive sensors + Low-cost sensors + Suitable for in car use - Results have to further validated with a larger sample - Small sample size - Used in laboratory research - Cannot be used together with Shimmer 3, which measures ECG
Tobi eye-tracking glasses	Eye-tracking light glasses	Medium	Yes	No	Vision based: mean fixation time	+ Very detailed documentation of operationalization, design and procedure - Calibration of eye tracker might be time-consuming - Eye-tracking glasses medium-intrusive - Not suitable for on-road real-time trials
EyeAlert	Eye tracking cameras on dashboard	Low	Yes	Yes	Vision based: eye, face and head tracking	+ Visual feedback and auditory/voice alarms + Works in all weather and road conditions + Small and portable device + Mounts easily on the dashboard - Sensitivity of the system
Delphi Electronics Driver Status Monitor	Vision-based single camera	Low	Yes	Yes	Eye-closures and head pose	+ Real-time warnings and notifications + Non-intrusive + Increases road safety + Offers the most direct indication of early distraction - Sensitivity of the system
SensoMotoric Instruments	eye tracking system, computer vision-based	Low	Yes	Yes	Gaze direction, head position, eyelid closure and PERCLOS	+ Quality product + Usability + Validation to obtain solutions that are truly focused on resolving an unmet need - User calibration is necessary
Toyota and Lexus' Driver Attention Monitor	Eye tracking cameras on dashboard, sensors	Low	Yes	Yes	face orientation and facial expressions	+ Provides flashing lights and warning sounds + Prevents frontal collisions, unintended lane departures and night-time accidents + Intuitive features for enhancement driver's awareness of surroundings - System may in some cases not operate properly due to a variety of road/vehicle/weather conditions - People and obstacles that show in the monitor differ from the actual position and distance
CarSafe application	Smartphone application, front-facing cameras, embedded sensors	Contact free	Yes	Yes	Lateral and longitudinal acceleration	+ Portable, scalable, upgradable and cheap device + Provides instantaneous driver feedbacks - Application is only available for Android phones - Low quality of the sensors - Are not fixed, leading to issues as regarding relative orientation, driver recognition and GNSS coverage

5.1. Limitations

A few limitations can be arguably found in the current literature with regards to the review and overall assessment of state-of-the-art real-time technologies for monitoring driver distraction. First of all, one limitation lies in the nature of the design of the works themselves. As mentioned above, the majority of the researches and systems investigated, were tested mostly in simulated environments instead of real driving ones, probably due to the danger of testing inattention in real driving conditions as well as due to the problems of vision systems working in outdoor environments (i.e. lighting changes, sudden movements). Driver's physiological reactions or movements, distraction or inattention may be different in a driver simulator from those in real conditions. Also, simulations are known to underrepresent on-road conditions, making them less representative and effective solutions, while drivers may not face the driving process seriously, or sometimes an extra discomfort may be added to participants, usually caused by simulator sickness.

Additionally, it is worth mentioning that most studies and devices examined, were used in cars and can be presumed to have been selected for their customizability. As there was not found any study concerning professional drivers in heavier vehicles, therefore, the findings may not be as useful to other transport modes. It should be also noted that eye tracking systems or devices operating with cameras in order to monitor the driver's eye movements or orientation may not function properly when the driver is wearing sunglasses. Furthermore, the functioning may be dubiously in extremely bright or poor light conditions as well as may be not effective for people with very dark skin and atypical facial shape. Technologies or wearables should be compatible with safety, prescription or sunglasses. There was also a noticeable lack of studies that focus on the indirect effects of driver distraction and inattention. For instance, the vast majority of eye tracking systems and cameras monitored the driver without detecting the road environment, such as a pedestrian crossing the street, road layout, traffic conditions, time of the day or weather (i.e. fog, snow, rain). Finally, it is worth noting that some technologies seemed very easy to use and handle with, but non-professional drivers and customers may be not able to buy them, due a high cost.

5.2. Future research directions

Undoubtedly, future scope of research would be to examine different state-of-the-art systems, products and technologies testing in real-time on road conditions, as the field validation would increase the reliability of the findings. Taking into account that simulators may provide contradictory, inconsistent and conflicting results and produce invalid research outcomes, systems should be validated in real conditions. Lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion and researchers must resort to identify which technologies for monitoring driver distraction or inattention are suitable to real-time naturalistic driving experiment. Due to the circumstance that each monitoring method or technique described above is not the one and only standard in research, a thorough testing in real-time conditions for different transport modes is indispensable. As all studies were conducted with devices resembling car interiors, therefore it could be beneficial to examine technologies that are able to detect buses', trucks', trains' or trams' driver distraction.

In future studies, technologies for monitoring driver distraction in real-time should be tested with bigger sample sizes and for longer periods of time. In this way, fuzzy knowledge base will be easier to be generalized. For instance, it would be a good idea to examine vision systems, especially in drivers wearing glasses in order to solve the problems for daytime operation. A combination of sensors, such as a steering wheel and a lateral position sensor in addition to the visual information would be beneficial to achieve a correct detection of driver distraction.

Finally, as the majority of measurements concerning distraction are frequently intrusive, in-vehicle personalization [48] or the correlation of driving behaviour data with visual measurements through advanced statistical or machine learning approaches could become beneficial. Such advanced methodologies have been found to be advantageous in many road safety aspects e.g. activity recognition [49], real-time conflict prediction [50], and its practical and more generalized application on driver distraction could bring new insights in how to tackle the problem for safe driving [51].

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.

Currently, there is no standard procedure for measuring the driver’s distraction, with a plethora of methods, indicators and algorithms, each with strengths and drawbacks. In most cases, driver distraction was measured in terms of its impact to driver attention and driver behavior [4]. The best studied forms of distraction were not only visual but also cognitive distraction. Non-intrusive technologies were strongly preferred for measuring inattention, and vision-based systems have appeared to be the most attractive one not only for drivers but also for researchers. In particular, attention monitoring systems, including real-time head, gaze and eye tracking systems, sensors on steering wheels, smartphone applications, wearables and dashboard cameras were found to be the most frequent devices to monitor and detect the driver's distraction, with head position, viewing and scanning patterns and PERCLOS being the most reliable indicators. On the other hand, less frequent approaches included hand magnetic rings and glasses. Non-intrusive methods were strongly preferred for monitoring distraction, and vision-based systems, providing physiological indicators, have appeared to be attractive for drivers. Nevertheless, complementing a specific technology with an Electrodermal Activity (EDA) measuring device, such as a Wristband or a (thermal) camera facing the participant will be beneficial, as the complementary method may provide evidence for validity.

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.

Systems aimed at increasing driver safety to be effective, an as accurate as possible risk monitoring instrument is required. This issue will constitute the project’s first pillar (i.e. real-time risk monitoring). 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. the i-DREAMS platform) could bring together these functionalities.

Within the i-DREAMS framework, the conclusions drawn from this study serve as the base for selecting appropriate measuring systems and devices for the future project work and for building the theoretical and mathematical model which are the backbone of the development of the i-DREAMS platform. Constructs to be measured are the driver's cognitive and affectional state (mental state) in terms of attention and distraction as well as more stable characteristics which are known to impact safe driving. Another outcome will be a research database with rich information of simulator and on-road drives of hundreds of participants. Since the database aims to facilitate future research, it can be argued that the more known about the test subjects, the better. However, this is a question of time, resources and also reasonableness towards participants volunteering to support the i-DREAMS research.

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