Driver Drowsiness Detection: A literature review and study on the contribution of signal fusion to ADAS systems

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ABSTRACT

The Driver Drowsiness Detection (DDD) feature is responsible for detecting driver fatigue, alerting them and preventing potential accidents. Drowsiness while driving can be detected in several ways, one of which is based on the typical behavior of the driver and the vehicle during such events, such as unintentional lane departure and steering wheel movement. This specific behavior of the car and the driver generates patterns that can be monitored and identified through sensors and modules that perform signal fusion and act to carry out preventive actions. This paper aims to review driver fatigue detection methods and analyze how signal fusion can increase the reliability of Advanced Driver Assistance Systems (ADAS) features, evaluating their benefits and obstacles. Additionally, regulations in Brazil that encourage the combination of advanced functionalities, such as the guidelines of Latin NCAP, will be addressed.

1. INTRODUCTION

The 2023 Yearbook of the Federal Highway Police (PRF) indicates that the two main causes of traffic accidents in Brazil are delayed reaction and the driver's absence of reaction. Additionally, the most frequent types of accidents are collisions, followed by running off the road [1]. Fatigue and drowsiness contribute to these scenarios as they slow down drivers' responses to stimuli and impair concentration while driving, increasing the likelihood of distraction and loss of situational awareness [2], which are major contributing factors to accidents

In this context, ADAS features are technologies that prevent human errors and assist in driving, using sensors, cameras, and software integrated into the vehicle. DDD is a functionality that identifies signs of sleep and fatigue, alerting the driver to prevent accidents. Detection occurs in two ways: directly, through an internal camera that monitors head movement, the time between blinks, and distractions; and indirectly, by analyzing vehicle behavior patterns such as deviations in trajectory, abrupt movements, and variations in speed, inferring the driver's state of alertness.

In ADAS, signal fusion involves combining data from multiple sensors and vehicle systems to create a more accurate representation of the driving environment and vehicle state. This technique overcomes the limitations of individual sensors, providing more reliable information for driver assistance systems [3]. The benefits of data fusion in ADAS can enhance performance in adverse conditions and contribute to the development of safer functionalities [4].

This article investigates how data fusion between DDD, especially in its indirect approach, and other ADAS functionalities, such as Lane Keeping Assist (LKA), Autonomous Emergency Braking (AEB), and Adaptive Cruise Control (ACC), can enhance road safety. Chapter 2 explores the methodologies of DDD, Chapter 3 addresses data fusion applied to driver assistance systems as well as its benefits and challenges. Chapter 4 discusses how indirect DDD together with the aforementioned ADAS functionalities can be improved. Chapter 5 addresses regulatory initiatives to promote safer vehicles.

2. DRIVER DROWSINESS DETECTION (DDD)

The driver drowsiness detection system utilizes technologies to monitor and identify early signs of fatigue and microsleep, in order to prevent accidents caused by decreased attention. The following will highlight the two main methods of DDD, which are fundamental to the effectiveness of the system and its integration with other vehicle safety functionalities.

2.1 DDD – Direct Method

The DDD based on the direct method, also known as Driver Monitoring Systems (DMS), uses an internal camera to continuously capture images of the driver's face, as illustrated in Figure 1. The images are processed by computer vision algorithms that utilize deep learning to extract facial and ocular features [5]. These algorithms identify and track elements such as eye contours, eyelid position, eyeball movement, and mouth opening. The system analyzes temporal sequences to quantify parameters such as blink frequency and duration, yawns, and head stability. Variations in these parameters, relative to a baseline profile of the driver or fatigue patterns, trigger alerts when signs of drowsiness or distraction are detected in real time [5].

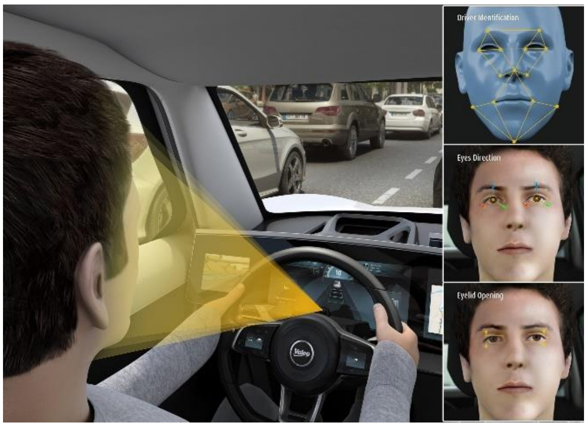

Figure 1: System for Monitoring Driver Drowsiness Signals. Available: https://www.valeo.com/en/driver-monitoring/. Source [12].

2.2 DDD – Indirect Method

The indirect method analyzes vehicle behavior through sensors that assess the driver's state of alertness in relation to fatigue. After defining the driving profile, the system continuously monitors sensor signals in real time, comparing them with the learned pattern. Angle sensors installed on the steering wheel capture the frequency and amplitude of the driver's corrections, while wheel speed sensors and accelerator and brake pedal position sensors monitor longitudinal dynamics, revealing inconsistent acceleration and braking patterns. The algorithms apply thresholds and statistical models to quantify these deviations and determine when driving behavior deviates from the pattern, triggering an alert to the driver [6].

Figure 2 illustrates the operation of the method, which uses vehicle behavior data as input to learn the driver's driving pattern through deep learning. As output, the system emits an audible, visual (represented by a cup and a message suggesting a break), or tactile (with vibration in the steering wheel or seat) alert upon detecting abrupt changes that indicate a risk of fatigue.

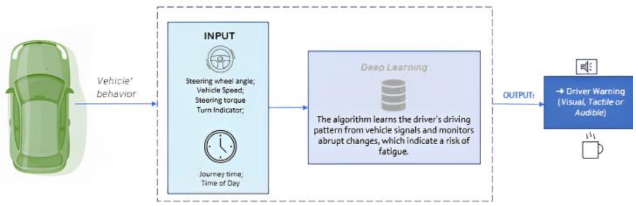

Figure 2: Fatigue detection system: Indirect Method. Source: the Author.

3. RELIABILITY IN ADAS: BENEFITS AND OBSTACLES OF DATA FUSION.

Currently, ADAS functionalities operate predominantly in an isolated manner, each depending on specific sensors such as radars, cameras, or ultrasonic devices, and on its own Electronic Control Unit (ECU). This architecture, while functional, frequently exhibits inaccuracies and sensitivity to external factors. Furthermore, the failure of a single sensor that is essential for multiple systems can result in the failure of all those systems [7].

The fusion of ADAS features refers to the integration of multiple driver assistance systems to create more robust, efficient functionalities with a more holistic understanding of the environment around the vehicle. Additionally, data fusion opens pathways for autonomous driving, bringing us closer to a scenario where cars can drive themselves on highways with minimal human assistance [5]. However, there are challenges that need to be overcome related to the complexity of integration, costs, and validation, which are fundamental to realizing these benefits

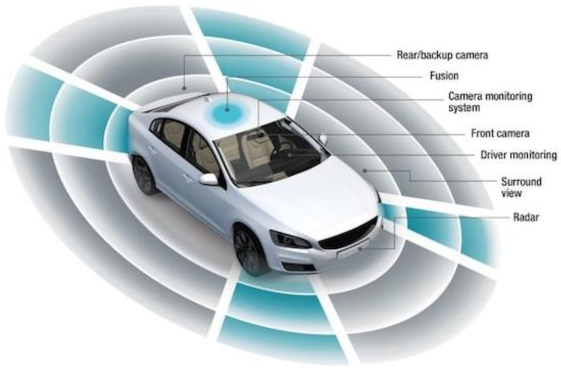

Figure 2: Example of ADAS fusion. Source [9]

The following aspects are applicable to the benefits of data fusion systems:

- **Complementarity:** Multiple sensors are capable of expanding the monitored area around the car and provide independent measurements of the characteristics of the same object, such as its location and speed. Additionally, the combination of sensors with different strengths makes it possible to overcome ambiguities that an isolated sensor might present.

- **Redundancy and Robustness:** Increased system reliability, allowing others to provide complementary information in case of failure or obstruction of a sensor, as well as improving measurement accuracy and increasing the fault tolerance of the overall system, preventing the failure of an individual sensor from causing the failure of the entire system.

- **Time Precision:** Through parallel processing of information from each sensor, the acquisition speed can be increased.

- **Better Understanding of the Environment:** The fusion of sensory data provides a more complete and accurate view of the vehicle's surroundings, resulting in safer and more assertive decisions.

- **Vehicle Safety:** Vehicle safety can be significantly enhanced by data fusion systems, as these make vehicles inherently safer.

Conversely, there are aspects that challenge data fusion systems:

- **Data Integration:** The more sensors that are monitored, the more complex the data fusion task becomes. Depending on the type of fusion, the temporal and spatial alignment of data from different sensors can be problematic; timestamps, communication delays, and sensors that are biased against each other (e.g., susceptible to temperature variations) can generate information noise and cause failures. The work in [8] presents data processing and feature extraction techniques that can address these problems.

- **Network Requirements:** The communication bandwidth can be considerably increased, making it necessary to have more communication channels and additional electronic components.

- **Hardware Development Costs:** With multiple sensors, there is a need for more powerful processing units, which leads to an increase in the development costs of these components. To mitigate this challenge, article [7] presents and discusses two processing approaches: centralized and decentralized.

- **Validation and Testing:** Testing and validating the safety and reliability of fused systems is more complex than testing individual systems, requiring more comprehensive test scenarios and more appropriate infrastructure.

In summary, while data fusion in ADAS promises safer vehicles, enhanced environmental perception, and the advancement towards autonomy, it faces challenges in complex integration, hardware costs, and rigorous validation; however, the benefits of complementarity, redundancy, temporal precision, and regulatory compliance drive the overcoming of these obstacles for safer and smarter mobility.

4. DATA FUSION BETWEEN DDD AND ADAS FUNCTIONALITIES: LKA, AEB, AND ACC

According to [6], there are several ways to detect driver drowsiness; one of them is based on the behavior mentioned in Section 2.2. This specific car and driver behavior creates patterns that can be monitored and detected through sensors and modules that fuse signals and act to perform preventive actions.

DDD using the indirect method can work in conjunction with the functionalities of AEB, LKA, and ACC, receiving the signals from these modules as inputs for the fatigue detection algorithm. At this point, the algorithm receives the signals, analyzes the data, and compares it with the driver's standard driving pattern; if the detected signal is outside the analyzed pattern, the system triggers the output signal.

AEB, LKA, and ACC are functionalities that fall, according to [6], under Standard Deviation of Lane Position (SDLP), where the central objective behind them is to monitor the relative position of the car within its lane using an externally mounted camera. The embedded software in the module of these functionalities is responsible for analyzing the acquired data and calculating the vehicle's position in relation to the center of the lane. In this way, unintentional lane departure information is obtained.

However, this information alone is not sufficient for the decision-making of the indirect DDD algorithm; therefore, in most cases, a steering wheel angle sensor is used, making it possible to mitigate corrections in the steering wheel position, however small they may be. When the driver is drowsy, these corrections tend to increase.

Both SDLP systems and the steering wheel angle sensor have their limitations. In the first case, cameras are always susceptible to road markings, lighting conditions, and weather. On the other hand, the steering-based system is affected by the geometric characteristics of the road and can generate many false positives. The fusion of these systems for indirect DDD increases the complementarity of the system as a whole, making it more reliable, accurate, and less prone to failures and false positives.

5. REGULATIONS IN BRAZIL

The combination of ADAS functionalities is being indirectly encouraged by the growing demand for vehicle safety. Automakers and their suppliers are continuously stimulated to develop new and safer technologies through incentives such as the MOVER (Mobilidade Verde e Inovação) program, the successor to ROTA 2030, which indirectly promotes the combination for more complete and safer systems.

In Brazil, resolutions are being developed to establish the mandatory nature of systems such as AEB and LKA, which naturally encourages the integration of multiple sensors and ECUs for the effective operation of these systems. In the context of Driver Drowsiness Detection (DDD), there is still no regulation addressing the mandatory nature of this functionality in vehicles; however, the European Union has been a pioneer in this area with the publication of [11].

Furthermore, Latin NCAP does not have, in its new Safety Assist v.2.0.1 protocol, which will come into effect from January 2026, its own testing protocol for the evaluation of DDD, adopting the requirements of Euro

NCAP implemented from 2023. However, the new Safety Assist v.2.0.1 protocol establishes the presence of AEB and LKA in the evaluated vehicle as a prerequisite for the DDD score [9], naturally promoting the combination of functionalities with DDD using the indirect method.

6. CONCLUSION

This article proposed a review of driver drowsiness and fatigue detection methods, presenting the direct and indirect systems. The benefits and obstacles of data fusion were mentioned, as well as how the fusion system can increase the reliability of DDD using the indirect method. The approach to regulations in Brazil showed that there is still a path to be achieved by regulatory bodies in the face of technological advancements that address the combination of functionalities that are one step ahead. In the future, it would be relevant to conduct a case study of the implementation of DDD with the presented resources.

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