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A Review of Artificial Intelligence Applications in Vehicle Safety and Driver Assistance Systems

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Abstract- This paper summarizes advances in intelligent technology to enhance road safety with an emphasis on increased use of systems to detect car accidents. It reviews previous studies involving image processing, sensor-based systems and the combination of artificial intelligence and deep learning (AI with DL). It was proven that the latest systems use combination of sensors (like accelerometer, GPS, video, etc.) and Advanced Drivers Assistance Systems (ADAS) for better detection and less errors. This study shows that AI and DL have the ability to improve the speed and quality of processing data in accident scenarios. It also addresses data, system reliability, and practical aspects to improve the effectiveness and safety of intelligent accident detection systems in evolving road transport technologies. It also identifies research gaps and provides the basis for subsequent studies.

Keywords: Artificial Intelligence, Automobiles, Advanced Driver Assistance Systems (ADAS).

I. INTRODUCTION

Global concern over the rising number of traffic accidents has increased, particularly on single-carriageway and interconnected highways, where severity of accidents and fatalities is high. Some of the causes of these incidents are lack of infrastructure, increasing traffic on regular roads, and unsafe conditions for drivers, while rising concerns about energy use and emissions emphasize the need for innovative and implementable solutions [1].

A notable technological innovation for the challenges posed in the automotive industry are the Advanced Driver-Assistance Systems (ADAS). They enhance efficiency, safety, and comfort while driving by integrating sensors, AI, and control systems. These systems take over essential driving functions and provide warnings. As such, they decrease accidents arising from human mistakes and errors, including driver fatigue, distraction, and poor judgment [2].

Today's vehicles utilize technologies like radar, lidar, and computer vision to identify obstacles, understand road situations, and assist drivers to make safe driving choices. Intelligent transport systems (ITS) and smart vehicles have evolved from providing reactive safety measures to predictive and adaptive safety measures [3]. Intelligent transport systems (ITS) and smart vehicles have evolved from providing reactive safety measures to predictive and adaptive safety measures [4].

Road accidents are primarily caused by human mistakes, including fatigue, distractions, and stressed driving, especially with long hauls and commercial driving [5]. Regarding road accidents, driver behavior monitoring systems based on machine learning and image processing are used to identify and notify abnormal driving behavior on the spot [6].

Significant changes have occurred in the automotive industry in the last several years, especially in developing countries, due to the incorporation of AI technologies in manufacturing, design, and driving systems [7]. Apart from the safety aspect, AI is also used in the automotive industry for the enhancement of financial and operational management, thereby impacting the industry positively in these areas [8].

These developments further reinforce the belief that AI can assist with more positive driving behavior and less negative driving behaviors, i.e., accidents. In addition, scholars have applied machine learning and data analytics to enhance the features of Advanced Driver Assistance Systems and to attain improved and more nuanced insights on patterns of accidents. [9].

Additionally, advancements in fully autonomous systems have brought both positive and negative impact relating to safety, reliability, and ethical concerns [10]. With the advancement of modern technology, the goal is to create a connected ecosystem where the vehicles, the drivers, and all the components of the infrastructure can communicate in real-time to enhance safety on the roads [11].

Besides providing warnings about potential threats and, in some scenarios, acting autonomously to avoid collisions, automatic accident prevention technologies enhance the decision-making process of users. As such, driver assistance features have shifted from being a collection of features to tools that significantly influence consumer drivers and overall market rivalry [12].

II. LITERATURE REVIEW

This section provides a summary of the recent literature that focuses on ADAS research in perception, control, safety, cybersecurity, and the human aspects to further the field of intelligent vehicles.

Huval et al investigated that earlier ADAS perception research relied on fusing vision with sensors (e.g., radar, LiDAR), aided by motion and road models, these methods failed to scale to a wide range of driving situations, and they were highly hand-engineered. With the development of deep learning, particularly Convolutional Neural Networks (CNNs), the research has shifted to data-driven perception systems, which can learn complex visual features directly from images. CNN-based object detectors such as Overbeat and R-CNN demonstrated substantial improvement compared to traditional deformable part models. Other studies found that real-time lane detection can be achieved using CNN-based object detectors [13].

Enders et al explored that ADAS were later expanded to consider vehicle dynamics and ride characteristics, and particularly as cars become increasingly automated and occupant comfort becomes more significant. Studies on active and semi-active suspensions have shown that sophisticated control schemes can balance the trade-off between ride comfort and road-holding ability. Skyhook control, adaptive control, and Model Predictive Control (MPC) have been studied to maximize suspension responsiveness under system limits, but many of these studies neglect real-world actuator constraints, such as force and rate limitations. While recent research has demonstrated that actuator dynamics can dominate the comfort attainable, implying that actuator hardware capabilities must also be considered in addition to controller design. Although objective comfort measures such as RMS body acceleration and ISO standards are often used, the relationship between these measures and subjective comfort is poorly understood [14].

Payre et al examined, as ADAS systems evolved, the emphasis shifted from purely functional performance to cybersecurity and system interface reliability. Research has shown that non-automation-related issues such as ransomware or quiet display failures could significantly erode driver confidence in automated systems. Drivers often initiated manual takeovers without a system request, which led to poor vehicle control and safety risks. Participation in non-driving-related tasks (NDRT) was identified as a behavioral indicator of automation trust [15].

Rödel et al inspected continuing the human-centered perspective, the UX and UA literature has demonstrated that higher levels of automation do not always correlate with higher levels of user satisfaction. Using scenario-based assessments aligned with levels of autonomy found in current cars, researchers found that moderate levels of automation achieve the greatest acceptance, and even when ease of use is held constant, perceived control and driving enjoyment decrease as autonomy increases. Prior experience with ADAS positively impacts trust and acceptance of advanced automation, and perception is also affected by demographic factors such as age, gender, and driving frequency [16].

Francillon et al studied the security flaws in vehicle access systems, such as those in Passive Keyless Entry and Start (PKES) systems, broaden the scope of ADAS-related issues. Researchers have shown that cars can be tricked into unlocking and starting without the smart key present by relaying low-frequency and ultra-high-frequency transmissions around proximity assumptions in current designs, which can be circumvented and are unaffected by the strength of the encryption. Experiments conducted on multiple car types have shown this vulnerability to be cheap, feasible, and independent of the encryption quality [17].

Jansson et al analysed the collision avoidance and mitigation remain the top objectives of ADAS research, utilizing obstacle detection and risk assessment systems based on radar, lidar, and vision technologies in conjunction with probabilistic and deterministic decision-making algorithms, such as Collision Mitigation by Braking (CMBB), which holds promise to reduce the severity and injuries of accidents [18].

III. OVERVIEW OF METHODOLOGIES

This section outlines a methodology that centers on Advanced Driver Assistance Systems (ADAS), including the various angles regarding perception robustness, intrusion protection, secure connected vehicles, prediction of vehicle trajectories, and integration of technology at the system level.

Houenou et al analysed that ADAS and the prediction of vehicle movements and driver intentions in real-time, complex traffic scenarios, where studies integrate motion-based prediction models with the Constant Yaw Rate and Acceleration (CYRA) model and the Maneuver Recognition Module (MRM). Perception systems, such as location, velocity, acceleration, and yaw rate sensors, provide input into the geometry of a lane as detected by lane detection models. In the Frenet coordinate system, possible trajectories for the vehicle are calculated using cost-based functions that take into account passenger comfort and time efficiency, and these calculations are constrained to a given time frame. The outputs of the motion model are fused with a weighted fusion of the outputs and selected optimal trajectories from real driving datasets, to validate the model for different driving situations in ADAS and to improve the predictive accuracy for both short-term and long-term trajectories. [19].

Assessed the security posture of integrated ADAS architectures, including predictive capabilities and potential system weaknesses, which involves a thorough investigation of automotive components such as central gateways, telematics control units, and infotainment systems to map out the communication flow, with hardware and software reverse engineering to identify potential points of attack. To identify potential points of attack, hardware and software reverse engineering is used. During controlled penetration tests which simulate real attack scenarios, some of the interfaces tested which put the system under threat included USB, Ethernet, OBD-II, and cellular communications. To illustrate the continuum of potential exploitation, the in-car networks, especially the CAN bus, are shown to grant unauthorized access. After an assessment of the defense measures and updates to the ADAS-enabled system, test vehicles were subjected to remote and physical attack vectors [20].

The paper assesses the reliability of perception modules through deep learning-based vision models with adversarial and environmental perturbations, simulating variations in distance, angle, and lighting conditions that affect traffic sign recognition systems with Robust Physical Perturbations (RP2) and realistic synthetic and physical changes generated by distribution-based sampling techniques and spatial masking to ensure perturbations are confined to relevant objects. Controlled laboratory studies and real-world field testing using moving automobiles are used in two stages of evaluation to produce and test optimization-based adversarial inputs, and misclassification rates under different conditions reveal the robustness of ADAS vision systems [21].

Observed a structured literature-driven study of developments in autonomous and connected car technologies that support ADAS, which transitions from component level to a larger technological ecosystem that is reviewing research publications, technical reports, and scientific databases to understand advancements in perception systems, localization, vehicle control, V2X communication, IoT integration, and digital twin simulation by comparing the indirect contribution of battery systems, propulsion mechanisms, and power electronics to ADAS efficiency and discussing data-driven decision-making, trajectory planning, and behaviour analysis, research gaps, and real-world implementation issues [22].

Paper address internal anomaly detection as well as external threat assessment through deep learning-based intrusion detection systems. These predictor-based and encoder-decoder models are trained on normal vehicle trajectory data recorded in simulation environments, and stealthy attacks are artificially introduced by modifying input data while maintaining physical consistency to avoid rule-based detection. Sliding window techniques are used to generate real-time anomaly scores, and performance is assessed using F1-score and accuracy metrics. This approach illustrates how intelligent monitoring enhances safety in vehicle-following applications such as cooperative and adaptive cruise control [23].

A secure-by-design ADAS development is ensured by integrating a cybersecurity engineering process that includes Threat Analysis and Risk Assessment (TARA), which identifies and prioritizes vulnerabilities, and the STRIDE and DREAD models that classify threats based on likelihood and impact. While data flow diagrams identify attack surfaces throughout sensors, perception modules, and communication interfaces. Mitigation techniques for confidentiality, integrity, and authentication are recommended, and the method spans system lifecycle stages from design and development to runtime monitoring, as mandated by ISO/SAE 21434 requirements to ensure ongoing cybersecurity assurance in ADAS environments. [24]

IV. LIMITATIONS

Most reviewed studies present interesting insights and describe research databases that reveal noteworthy improvements, but certain weaknesses continue to be present and/or documented in each study. In much of the literature, the experimental setup involved controlled/semi-controlled environments to which light, camera or subject behavior are preset, creating concern regarding the ability of such systems to adapt to real world driving situations, which can be chaotic and variable in nature. In addition, many studies in the literature utilize too narrow or scaled datasets that are limited in variability in driving behavior, environment, and demographic.

This variability directly impacts the robustness of the proposed model. Because the result of performance measures are largely dependent on the context and are not directly on the literature, added variability in the context makes measuring/methodologically comparing various approaches in the literature exceedingly challenging. Another area of concern is the computational complexity of the proposed methods. Many proposed methods that utilize Deep Learning or Hybrid methods are achieving success but the tradeoff is high (memory and/or CPU) demanding real-time implementation (which is especially critical for on-board or embedded systems). In addition, real-time performance remains an area that has not been solved (e.g. poor light, occlusion (mask/sunglass wear), head pose dynamics, and high motion). So far, literature has tendered studies that do not fully solve these problems.

Finally, while single methods may succeed in few areas, their flexibility and longevity across different real-world scenarios remain unproven. Despite these limitations, the merits of the current work are growing as it provides the basis and proposes the essential avenues for future research aimed at improving reliability, efficiency, and practicality.

V. RESEARCH GAPS

While this area has developed considerably, there is still significant gap in research on building models that are extremely precise, and that prove to be reliable in a multitude of real-world practical situations. Many of the prevailing methods operate adequately in specific or controlled situations but struggle to sustain performance in real world situations involving situational changes such as driver unpredictability, interruptions, and changes in lighting. The datasets, frameworks, and evaluation methodologies in their current state are showing inconsistencies, and this slows down the effective transfer and adaptation of findings. A further significant research gap is the performance of these systems when integrated in real time as lightweight deployments. These are all the factors that affect the formulation of systems that are practical, solid, and dependable to meet the requirements of real-world problems.

VI. CONCLUSION

This review focuses on the effect of AI and DL on ADAS evolution and its integration with safety sensors, driver monitoring, and the vision and motion prediction model, as well as lane detection and CYRA and MRM trajectory prediction, real-time video, radar, and LiDAR perception, and human factors such as driver behavior, user trust, and automation acceptance and their impact on the human side of ADAS effectiveness. Despite progress, challenges like dataset variability, limited computation, and the gap between controlled and real-world scenarios persist. As AI-based ADAS initiatives continue to develop, it is clear that these projects will help reduce collision incidents and improve the intelligent transport system, but robustness, integration, and real-world deployment still need more work.

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