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From Reactive to Proactive: Employing AI and ML in Automotive Brakes and Parking Systems to Enhance Road Safety

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Abstract: ***Our comprehensive Machine Learning (ML) and Artificial Intelligence (AI)-based patent analysis in braking, parking, and related technology areas will reveal the most significant opportunity clusters relevant to these domains. We can use predictive analytics to forecast the development of currently identified opportunity clusters, employing an innovation competition model. This paper is organized as follows: In the first two sections, we systematically reveal how mature ABS, ESC, and parking technologies have settled in the global automotive market, using extensive patent data between 1966 and September 2019. In the third section, after disclosing the structure of our Telecommunications Engineering Centre (TEC), we detail our AI and ML analysis, focusing on the domains determined by our patent categorization strategy. Finally, the last section gives a high-level concluding discussion, summarizing the present approach and its significant contributions. Safety has always been a priority in designing and developing automotive systems. For instance, the function of an anti-lock brake system (ABS) is to prevent the wheels from locking up, thus enabling the driver to maintain steering control. Since its invention, ABS has become a standard safety feature in all vehicles. Since 2019, 65% of passenger car production globally has been equipped with some ABS. Most of ABS development has been accomplished by adding mechanical, electrical, and hydraulic components to vehicles. Although hardware development, like sensor technology, is essential, many breakthroughs have been achieved by inventing a control technique for ABS: FI (complete integral) control in 1978. This success has introduced disproportionate amounts of Intellectual Property (IP) around control algorithm innovation to bring more ABS products to market. Over time, competition occurs in other domains, such as the control algorithm, sensor technology, and system integration, and customers are looking for algorithm innovation to bring them better performance, lower cost, and compact solutions.***

Keywords: Automotive Brakes, Automotive Parking, Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Smart Manufacturing (SM

1. Introduction

One of the functions of a modern vehicle is the Parking Brake (PB), which is crucial for safety. PB is designed to hold the vehicle in place on inclines and can be actuated in both stationary and running conditions. It also serves as a drum brake system with a handbrake function. Developing automatic actuation systems is vital to minimize human intervention and improve safety. Real-time data availability is essential for developing AI and Machine Learning models to enhance safety measures. These systems have been successfully integrated with Adaptive Cruise Control and Automatic Emergency Braking to transform them into predictive and preventive systems, enhancing road safety. Road safety is a significant concern in the current high traffic volume age. Modern vehicles have various safety systems, including active braking systems such as Adaptive Cruise Control and Automatic Emergency Braking. These systems maintain a safe distance from lead vehicles and automatically apply brakes to prevent or mitigate collisions. Deep learning models have shown success in intelligent systems by combining reinforcement models.

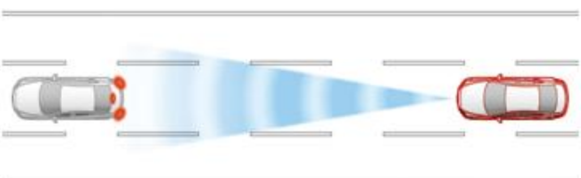

Figure 1: Automatic Emergency Braking System

1.1 The Role of AI and ML in Automotive Brakes and Parking Systems

AI systems in automotive brakes and parking have brought about a transformative shift. Instead of relying solely on human input, AI systems are becoming increasingly proactive. AI systems could become entirely dependent on ML-AI systems to function. The role of brake systems has evolved from being a secondary component to active safety systems and now being a last resort. Engineers are now considering the balance between human and AI capabilities in reactive driver assistance. Similarly, parking assist systems have undergone a significant transformation, integrating AI. Cameras, sensors, and ultrasonic systems activate braking systems when an object is detected. With AI making independent decisions, there is no need to treat the system as reactive. The invention of automobiles was driven by the desire for speed and safer travel. Brake and parking assist systems initially served as reactive components to protect the vehicle and driver. However, technological advancements have allowed for more proactive systems that align with the driver's intentions while ensuring safety.

1.2 Advancements in Brake Technology

The Advanced Driver Assistance Systems (ADAS) technology trends to improve safety and reduce accidents. Safety features like ABS, EBD, ACC, LDW, CAS, AEBS, PAS, and TCS are focused in ADAS. The demand for automotive safety systems is rising due to global safety standards. ABS is a powerful system that offers safety and convenience by decelerating effectively and avoiding accidents. These features enhance the driving experience and reduce the risk of injuries. With technological advancements, companies can offer more efficient and cost-effective braking systems.

1.3 Integration of AI and ML in Brake Systems

AI and ML also present much potential in automotive components designed for the functions of brake systems, such as antilock brake systems and dynamic vehicle control braking. Vehicle brakes are reactive in that they only come into play when the driver applies them or when automatic braking systems come into action in response to some external input from the sensors built into the vehicles. In an absolute sense, all brakes work in a reactive mode – the vehicles slow down only after the brake force is applied. This force can only be applied when the driver or the automatic system detects an immediate threat. Thus, applying brakes only after the threat has been identified may, at times, have been too little too late. Antilock brakes have some proactivity where they anticipate skidding or wheels locking and easing off the hydraulic pressure. However, those systems may not work well enough under all conditions.

Automobile technologies aim to improve braking and braking systems from a proactive perspective. Integrating AI in braking systems involves including cameras, ultrasonic or radar sensors to detect pedestrians, other vehicles, or obstacles in the vehicle's front, sides, or back. Special brakes have also been designed to provide proactivity to the braking systems, such as by putting a more cushioned force on the brakes, strengthening the automatic braking system's functioning under these conditions. Also, significant progress is being made in brake-by-wire or electric brake systems, some of which derive their brake force entirely from electric energy and are highly controllable, undermining the reliance on hydraulic energy flow modulators. The data collected from such systems can be the source for predictive maintenance predictions and even for finding obscure performance trends that are not envisioned. Such datasets and more conventional ones can be a rich source for ML-based research.

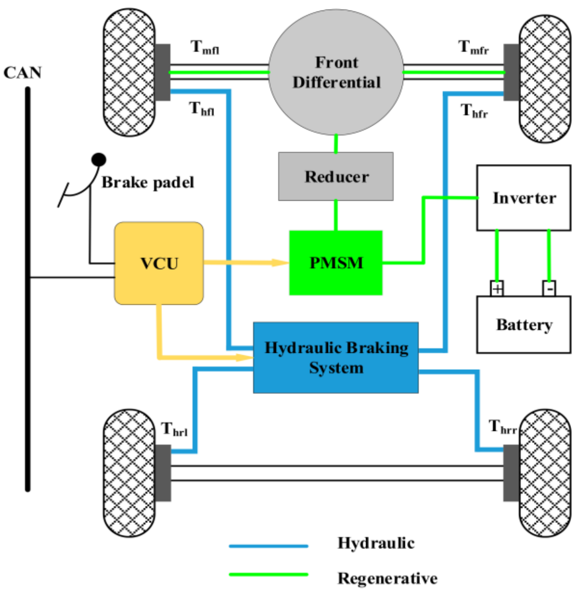

Figure 2: ML Approach to Braking System

1.4 Enhancing Parking Systems with AI and ML

Modern vehicles are outfitted with Advanced Driver Assistance Systems (ADAS) and intelligent parking systems, two main features enabling the development of autonomous vehicles. Several critical functionalities in intelligent parking systems, such as sensor-fusion and camera-based object detection and tracking (ODT), enhance a vehicle's situational awareness. However, current parking assist and safety-related systems predominantly extend ADAS capabilities.

Although there may be improvements in Intelligent Parking Assistance Systems (IPAS) and Automated Valet Parking (AVP), both are susceptible to individuals attempting to influence the electronic control unit (ECU) to gain unauthorized entry—some of which can lead to vehicle theft. Machine learning (ML) models, such as accuracy in referring to vehicle signage, brake state prediction, and vehicle detectors with YOLO (You Only Look Once), have proven reliable means of detecting objects in parking systems. Moreover, Zhou et al. devised an obstruction detection system to identify obstacles near vehicles because of their small size and opacity—features they share with the environment.

The authors propose an on-vehicle parking policy that determines in real-time which parking spaces are best suited for parking with the parking lot layout. Reinforcement learning trains the parking policy with on- and off-street parking spaces. Optimal control approaches have been widely used to design and optimize the ARS. Zhang et al. develop a control-oriented optimal policy for an ARS using a dynamic programming algorithm [9]. Du et al. propose an urban parking feature map construction method and an assistant parking positioning method based on the map. Cuzner et al. calculate an optimal speed profile.

Leonetti et al. propose a parking algorithm that extends the pre-existing literature focused on parallel and perpendicular parking and can be successfully applied to both on-street and off-street parking. Although the methods outlined above could also deploy camera sensor data to work (but the sensor data will not provide the level of information or distributed distances as AccuPark will), they provide different information or distributed distances. That needs to be more than those methods to solve both user problems stated at the beginning of this section. AccuPark computes the parking coordinates to increase the user's parking comfort and ease.

1.5 Benefits of Employing AI and ML in Automotive Brakes and Parking Systems

The impact of human-vehicle motion parameters and warning models on the rear DOW safety warning is analyzed using traditional methods. The selected models are tested for effectiveness and feasibility. Warning algorithms and a fuzzy controller are designed and simulated. Vehicle technology allows real-time detection and warning of safety information, improving vehicle security. ML is widely used in active car safety systems. The introduction of deep learning in perception systems is compared to traditional and ML methods. Automotive sensors are rapidly developing and becoming more affordable, leading to sensor-driven parts in vehicles.

1.5.1 Improved Road Safety

Road safety has been a long-standing priority worldwide, and as a result, remarkable progress has been made in recent decades. Employing Artificial Intelligence (AI) and Machine Learning (ML) in automotive brakes and parking systems to enhance load safety has the potential to provide a unique contribution to future efforts in road safety. This paper systematically explores using AI and ML to enhance road safety in automotive brake and parking systems. The main goal of this paper is to present the current state of the art in the development of intelligent braking systems in the automotive industry to attract the rest of the community's attention to developing more efficient and reliable systems. Unlike other review papers, we focus on the viable research contributions related to active safety braking systems where AI and ML algorithms have been employed. This paper thus applies AI techniques to developing intelligent braking systems in the automotive and parking-type braking system domain.

Designing and implementing efficient safety measures at the vehicle level is challenging due to ambiguities in environmental and human behaviors. In the past, active braking systems have been designed using different approaches, i.e., ultrasonic, laser, and stereo-vision, to detect obstacles. At the functional level, AI has also been used with braking systems to drive the driver's intentions. Several researchers have employed AI algorithms to predict the synthesis and classification of brake wear conductivity profiles or to apply predictive braking; therefore, consulting AI for active safety has not been philosophical but practical. This paper presents the explored types of AI employed in active safety systems. A paper specific to the subject has yet to be published; hence, this paper should be exceptional. The methodology becomes particularly important in determining what representation to use for environment and behavior ambiguities for system control at the vehicle level. This paper takes the initiative to target the braking domain from technology enablers in active safety-assisted parking, electronic stability controls, and crash reconstruction algorithms as taken.

Figure 3: Increased Road Safety through AI/ML Assisted Braking

1.5.2 Enhanced Vehicle Performance

An example of an electric parking brake system can be found in several electric vehicles. ECUSH-based systems generate Haptic feedback to the driver by minimizing gaps formed by the brake pads and disc rotors. Manufacturers are focusing on improving ESP systems through torque allocation. Fuzzy logic control techniques have been proposed to manage vehicle control strategies. The control system can robustly control the vehicle behavior during stationary cornering conditions. The adoption of an electric or electro-hydraulic booster offers significant advantages for lateral vehicle dynamics control. A vehicle model tailored to nonlinear Kinematics and Compliance properties should be developed for optimal handling performance.

1.5.3 Reduction in Accidents and Collisions

With the intrusion of sophisticated technologies such as sensors and radar and corresponding advanced software tools like machine learning and AI, vehicles have witnessed a revolution in their safety aspects over time. Vehicle manufacturers must focus on advanced braking technologies to further reduce the probability of accidents and the amplitude of damages due to the brakes' and components' contribution to obnoxious pollutants. Dual-pump, regenerative, anti-block braking systems, or 4-channel antilock braking systems (ABS) are some of the innovative brake systems that are making their way into vehicles. Accident detection systems based on an onboard device, such as autonomous vehicles, are majorly focused upon. One more category revolves around the machine learning models for accident detection systems. A significant drop in the number of accidents is observed for the systems that installed a list of endangered and vulnerable animal species that still exist in the valley despite the unfriendly situation created by humans. This indicates that implementing AI and ML in automotive brakes and parking systems has shown promising results in reducing accidents and collisions. However, automobile accidents still prevail on account of the inefficient braking systems associated with the vehicles. The specified times of different attenuation need to be worn properly, which causes the brakes to wear out considerably.

Furthermore, the defective machinery or the assembly of vehicles, i.e., shoes, rotors, drums, etc., also damages the brakes. In the context of the brake systems of modern automobiles, such circumstances must be captured as quickly as they arise. Their innovative machine learning (ML) and AI-managed brake systems can play a vital role in avoiding the chances of expected road incidents.

In the era of ML and AI-based trained models, the vehicle's brake system not only provides the most excellent possible braking efficiency on the vehicle, but these ML and AI Algorithms can predict the expected future schedule and period of inspection and maintenance jobs. Using the models above, such predictions are made under the conditions of the braking system systems, e.g., pedal forces, variable friction coefficients, varying slope angles, etc. The suggested training models of machine learning and artificial intelligence can predict the modern brake conditions on and off based on the onboard gathered or accessed accurate data sets at a time. AI-based sensor systems are more effective and efficient in recognizing it and provide expedient alarms for drivers to avoid road accidents by avoiding challenges and Future Directions.

2. Challenges and Future Directions

In this study, AI is used to automate the extraction of injury-relevant information from AEBS and BA messages. Rule-based techniques show high sensitivity but low specificity, which can be improved by adding contextual information. These challenges have gained critical attention and can be addressed through rule-based and machine-learning approaches. Wide-scale vehicle network control modeling includes safety, traffic, and customer experience. Accurate and efficient object detection, sensory data management, decision-making techniques, software validation and test components' reliability, infrastructure, network performance, handling diagnostic trouble codes, software updates, data regulation, privacy, and security issues are challenges in real-world application implementation.

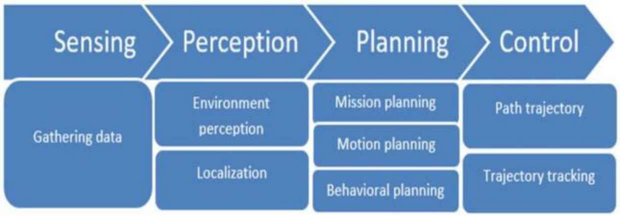

Figure 4: Future Pathways for Detection and Response

2.1 Ethical Considerations in AI and ML Integration

Recently, AI and ML have increasingly been integrated into automotive braking and parking systems to enhance road safety. This AI can self-learn through a machine-learning process and enhance identification accuracy accordingly. In other words, AI has transitioned from reactive to proactive models of control. Various automobile accident control, driver assistance, and intelligent driving technologies based on computer vision, lasers, advanced driving-assistance systems (ADAS), and LIDARs have been developed and applied in the intervening period. However, despite these advanced technologies, serious challenges still need to be solved, requiring a more proactive intermediate-vehicle model to ensure rapid, accurate, and robust control switching.

Since the early 1920s, various research institutes have exhibited high-level automotive cognitive algorithms. In Toglia, four traditional designs are presented in Figs. 1 and 2 contain four blocks: feature extraction, object detection, object recognition, and strategy selection. These conventional systems provide software safety to developers via rule-based approaches only. By contrast, integrating AI/ML vastly improved the detection algorithm, which processed the raw data via a different route. The AI/ML approach identifies the complex surroundings of the vehicle and successfully predicts the causative motivations for accidents. However, this reactive model still needs the traditional rule-based system for different actions related to possible system decisions after having predicted. If the vehicle is equipped with rule-based actions only, the system might miss the human-driver interaction; however, it is necessary for a vehicle to have a model-based AI/ML that interacts with the physical model of a vehicle to identify the essedrivers'ivers' reactions. For instance, in disturbing vehicles, the driver should assist the symptoms by counteracting as an initial response. There is a need for an intermediate model to reflect the complex drivers' reactions by modeling both the vehicle and human drives, considering human-cognitive development and path predictions, for achieving traffic safety in critical situations and preventing severe accidents.

2.2 Overcoming Technical Limitations

Academic labs, research bodies, and companies' research centers boost the diffusion of AI in organizations. Open-source initiatives aid with model life cycle coverage. Freely available frameworks like TensorFlow and PyTorch handle neural networks and AI and ML address technical limitations in certified systems. ML techniques reduce software development effort and integrate handcrafted modules. AI models can protect against vulnerabilities and software exploits.

2.3 Future Innovations and Research Opportunities

In the past decade, the body of work has emerged in vehicle safety, including vehicle cooperation and collision avoidance systems. One of the main challenges researchers and developers in the field have faced thus far is guaranteeing safe operational capabilities as close as possible to that ensured by expert human drivers. This is partly due to the rapid advancements in the data-gathering and processing methods that underpin these autonomous vehicles, primarily enabled through various Artificial Intelligence (AI) and Machine Learning (ML) algorithms. Due to the vast advancements in these technologies over recent years, autonomous vehicles have become more people-oriented and capable of predicting human behaviors, enhancing the comfort and overall user experience when driving/being transported amongst fully automated vehicles.

What has only been faced in a few papers, however, are ways to ensure the detection of vehicles already in near-collision scenarios, especially when vision-based sensors may not be able to detect them in standard Advanced Driving Assistance Systems (ADAS) use cases. This research study proposes using vehicle-based sensors, such as wheel speed sensors and seatbelt tension sensors, that may be used for detecting near misses and the culmination of factors lending to such near-miss scenarios. If a near miss is detected, the proposed research leverages cloud-to-cloud and Vehicle-to-Everything (V2X) communications to alert other vehicles or potentially snowy amb "ance "road management infrastructure." If other vehicles within the vicinity are alerted, they can adjust their locations to allow the snow removal automation arm to be operated in the acumen ambiance of the roadway. If no other vehicles are within range, then the other vehicle(s) may alert traffic management infrastructure of being incapacitated, and from there, an alert could be sent to a snow control worker to take necessary action, such as moving the vehicle or hailing part of the road to allow for traffic.

A few of the future innovations possible in the proposed research include the replacement of stereoscopy and radar sensors with computer much cheaper vision sensors with/without visible light and the use of more advanced AI/ML algorithms in order to predict in-ambiance vehicles better, even in the event of obstruction by moving vehicles or unexpected stopped vehicles in the path of a snow removal action.

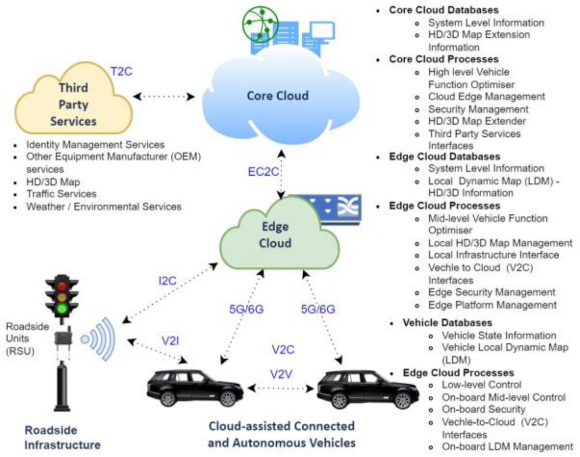

Figure 5: Cloud-Assisted Autonomous Vehicles

3. Conclusion

Regulatory bodies impose constraints on the accuracy of autonomous safety systems. Developing and regulating AI and ML-based autonomous vehicles have similarities and differences from conventional ones. Liability must be defined when an autonomous vehicle is involved in an accident, requiring an extensive investigation. Vehicle safety is crucial, with active and passive systems introduced. Active systems use sensors and processing to avoid accidents, and passive systems minimize injuries with damping materials and airbags. Autonomous vehicles introduce concepts like Infrastructure and Everything communications, with an intelligent system acting as an artificial driver using AI and ML approaches.

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