Leveraging AI for Dynamic Vehicle Control Systems

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1. Introduction to AI in Vehicle Control Systems

INTRODUCTION Fueled by the rapid advancements in computational hardware, sensor technology, and machine learning, AI is increasingly adopted for a wide range of vehicle functionalities. Seemingly ever-increasing levels of autonomy, advanced driver assistance systems, and predictive maintenance are entirely built upon AI methods. The automotive sector has seen a considerable history of AI and machine learning applications in the last two decades. A notable point at which AI showed its potential as a transformative technology in automotive was in 2004 when a self-driving car demonstrated its ability to perceive its surroundings and make decisions in real time.

Objectives and challenges. Systems of an advanced AI vehicle must continuously and efficiently process spatiotemporal data to act in real time. In comparison to implementing a more conventional manually designed system, the system should autonomously process real-time data to act in real time. Thus, AI vehicle systems are faced with challenges across various fields, such as machine learning, optimization, and control, among others. In the expansive automotive sector, in its various design and operation aspects, numerous AI vehicles or vehicle systems have been developed. A remarkable example is the work on autonomous robotic systems and predictive maintenance. In addition to these examples, AI ship autopilot systems and highly automated AI systems for drones and other vehicles have additionally been proposed. Taken together, these examples highlight the automotive sector's interest in self-optimizing AI systems. More recently, AI is increasingly used for adaptive vehicle control systems. For instance, AI has been shown to outperform rule-based predictive energy management systems, and drive cycles improved by AI-based gear shifting show increased accuracy.

1.1. Overview of Dynamic Vehicle Control Systems

Dynamic vehicle control systems play a significant role in automating the vehicle by regulating processes, energy, and coordination functions. Fundamentally, the gas, brake, and steering controls are utilized as process control elements to enhance vehicle operational performance. These controllers operate in synergy to guarantee the safety of vehicle occupants, other agents on the road, the vehicle itself, and the surroundings. Before vehicle control while maximizing the vehicle's potential, the following improvements have been implemented at different levels of the vehicle:

1) Enhancement in situational awareness for robust detection and tracking of pedestrians, vehicles, and other physical elements to determine their intentions and trajectories using onboard sensing systems such as cameras, LiDAR, and inertial measurement units. 2) Integration of a priori maps of the road geometry and traffic management systems for improved decision-making. 3) Prediction of near-future estimates for all agents in the surroundings to undertake proactive measures. 4) Utilization of machine learning algorithms to improve the computational speed of the vehicle to expedite autonomous decision-making.

Vehicle controllers are designed to actuate emergency stops, lane changes, and overtaking algorithms, among others.

The primary objective of dynamic vehicle control systems is to assist and provide support for human drivers during critical tasks or under limited roadway conditions, such as commercial drivers, truck and trailer drivers, and passenger vehicle drivers. Such high-level driving tasks could involve maneuvering the vehicle among a crowd (e.g., in parking lots or at airports), in all-road conditions (e.g., in off-road environments, construction zones, or mail delivery duty cycles), and tactical operations (e.g., during vehicle-following or while managing caravans while towing trailers). Control systems primarily design ownships in the vehicle at a lower level of control. A network of these sensors is utilized in concatenation to empower the onboard vehicle controller to adapt to the surrounding changes in real-time.

The utility of such perceivable elements in our framework is not intended to detect the surrounding participants but to execute proper functions. In this regard, many effective systems have been developed with embedded safety mechanisms that leverage either rules-based scripts or learning from human data to govern vehicle-to-vehicle interactions. These systems that easily blend with manual drivers have very useful application areas, such as advanced driver-assistance systems. Nevertheless, there is a legitimized need for building a new ecosystem with these data-driven techniques that can seamlessly blend with the dynamic vehicle controller and take over the low-level control of the vehicle under congestion to facilitate micro-mobility, e.g., activity-based models and driver diversity that are requisites for mobility-on-demand transportation systems for not only four-wheelers but also small shuttle buses, personal rapid shuttles, and low-speed electric human-powered cargo. A major challenge involved in the real-time execution of vehicle control systems, regardless of the underlying vehicle controller, is how the onboard vehicle controller can take advantage of the aforementioned elements to readjust the key parameters. Going forward, we will discuss the modifications in our vehicle control system that facilitate this additional fusion of onboard sensor data that is inhabited by data-driven techniques and how the vehicle can adapt for intersection entry curb using congestion envelopes in the vehicle control system.

1.2. Evolution of AI in Automotive Industry

The automobile industry has been integrating AI into vehicles for decades. Although initially, systems were very limited. In the 1960s, companies started adding early forms of cruise control and anti-lock braking systems into cars. A few decades later, AI parts of these systems became more complex and capable of autonomously performing some driving tasks. These early systems, however, were mostly traditional control systems with a minor part relying on neural networks for adaptive control. Since 2010, AI started penetrating deeper into vehicle control systems. In particular, several known automakers and tech companies have announced the introduction of car functionalities that rely on machine learning algorithms.

This trend represents an increasing convergence of traditional mechanical vehicle control systems with systems that rely on large amounts of data and advanced algorithms. Necessary to make this possible is the continuously increasing power of digital processors and sensors in vehicles, capable of performing complex operations on the go that require significant computing power and algorithms trained on real-world data. Chips with the ability to perform deep learning were not available until 2017. Hardware advancements have re-enabled model-based design and data-driven design within vehicles. The increase in the velocity of real-world training data collection was also a key driver of the trend towards AI-based control systems. The advent of connected vehicles rolled out a new market of selling data and cloud solutions that can provide cybersecurity, over-the-air updates, secure communication, data analytics, and autonomous driving upgrades. The transition from non-connected vehicles to connected will further transform the transportation market. In addition to technology advancements, regulatory shifts have also made approximations of training data with simulations key, as it is hindered to collect as much training data as was feasible prior to 2020.

2. Fundamentals of Adaptive Cruise Control (ACC)

2. Fundamentals of Adaptive Cruise Control (ACC) Adaptive Cruise Control (ACC) is a vital application of Artificial Intelligence (AI) in vehicle control systems. ACC is an enhancement over the conventional cruise control where the speed of the vehicle is automatically controlled based on the surrounding environment. An ACC is designed to maintain a driver-selectable headway from the vehicle ahead. Through the use of a sensor, an ACC is able to progressively retard the throttle or apply the service brakes to slow the vehicle whenever the headway to the vehicle ahead becomes shorter than the selected value, which can provide not only much driver convenience but can also bring safety benefits through earlier action to maintain a safe headway. There are a number of well-known technical systems that are components of some commercially available ACC systems, the best known being the radar sensors that are used to measure the separation and relative speed of the lead vehicle. In conjunction with this, either wheel speed or inertial sensors have been used to monitor the deceleration of the host vehicle in follow-up mode and to identify a stationary lead vehicle that may be re-accelerating away. It is not hard to contrast the operation of an ACC from the hardware perspective with the operation of a standard cruise control only in an increasingly dynamic world. Rather than operating with desired speed, the ACC operates with a predetermined command input for Longitudinal Vehicle Dynamics (LVD) control that has been developed as an output of the algorithms. ACC researchers globally have focused on the development of the enforcement of following vehicles to a target headway, or vehicle spacing, and the accuracy of speed and separation of desired, ensuring the longitudinal dynamics of the host vehicle reach a prescribed equilibrium point. Recent research has concentrated on the development of robust algorithms to prevent time delay and prove the effectiveness of the algorithms in terms of vehicle response, making systems scalable and applicable under any traffic. ACC has been identified to be very beneficial for highways; the application of the technology has been

successful in testing for congestion and arterial roads. As a very simple objective, the path planning algorithm is based on a sensory fusion concept effectively taken from the current literature. This acts as a basic fundamental concept applicable to most Intelligent Transportation Systems. Each free car path ahead is then planned from the combination of the free space and the position and size of the target vehicle with respect to the lead vehicle, both obtained from a fusion of the radar and camera sensors. ACCs have shown great potential to implement AI in vehicle control systems. The components of the system are actively dynamic and adaptive at a superior level. However, the utilization of the systems has brought concern worldwide as the applications of these systems are under fragile environments. This has, however, given a boost to new ways to research and develop Intelligent Systems in Vehicles. ACCs have penetrated the Intelligent Transport System concept to ensure that there are various applications Passenger and Commercial Vehicles can be utilized for. ACCs are implemented using more advanced vehicle following method algorithms that will guarantee stability and robustness of the headway control; however, this can only be possible if vehicle dynamic models are available.

2.1. Principles of ACC

2.1.1 Introduction to ACC Adaptive Cruise Control (ACC) was initially conceived as a successor to regular cruise control systems and was designed to fill in the gaps that regular cruise control systems had by offering users control and adjustment capabilities. ACC has the ability to extend or shorten the following distance between the vehicle and the preceding vehicle in an automatic manner by processing sensor data. These sensors are usually coupled with computer vision technology as well as GPS location data, and high-performance embedded systems like microcontrollers and microprocessors are used to compute and adjust following distances based on this sensor data. When requisite data from sensors is missing, due to inclement weather conditions or long-range travel and absence of available GPS data, ACC defaults to the minimum following distance applicable. The ability of ACC to carry out a task by combining data from different sensors and adjusting speeds in nearly real-time makes it complex. Special algorithms are needed to process this data accurately under conditions of heavy fog, rain, and other phenomena that cause larger uncertainties. Control theories that are implemented as PID, fuzzy control, and artificial neural networks predict the actions of other vehicles in the near future. Advanced ACC technologies using graph mining, Markov models, Kalman filtering, particle filtering, etc., can provide better insight and behavior prediction capabilities for the vehicle. Also, driver interface integration can make the system a little more robust and perform better by asking for input from the driver for desired following distance and social limits. Driver reactions and corrections are then integrated into speed control systems. ACC control is by no means an easy task because driver behavior, especially in an ACC environment, continues to be complex. Moreover, the system also needs to moderate with different speed limit changes and traffic density limits of roads. ACC applications for highway traffic are capable of being connected by using vehicle-to-vehicle communication channels or vehicle-to-road infrastructure communication. ACC can function even on mountainous winding roads, especially if enough data has been stored a priori in the system; it can be combined with traffic sign recognition and lane-keeping systems. ACC is also capable of handling real-life scenarios, including varying traffic flow among lanes, local speed limits, and changing road conditions.

2.1.2 Technical Challenges of ACC ● ACC is highly dependent on sensor system reliability and accuracy. ● Data extracted from sensor systems can have big variations due to rough weather, especially from near-mounted or transmitting sensors, and thus are highly uncertain. ● At high speeds, planning control systems for ACC algorithms might force large steering and aggressive maneuvers, which the driver would not normally appreciate as safe and secure. So, aggressive control inputs that are not responsive to real-life harsh transition states are impossible to implement. ● ACC is highly dependent on subsystem inputs like vehicle dynamic stability system inputs; also, hydraulics could deepen uncertainties and might need to be modeled for intelligent control algorithms. ● ACC does not yet have the capability of doing relevant on-road real-time license plate recognition, insurance data records, on-road sensor checkups, and standard authorities checkups. These inputs are essential for the system to work on bad behaviors like careless driving, high-risk driving, and many more. The only person still in command in this era of car history is the driver. It would also need to include mobile wireless standard communication ports or high-tech automated vehicular safety standards. ● ACC could continue steering inputs if local authorities would not place potential threats like high transitions with speed limiters or city highway barriers.

2.2. Types of ACC Systems

In commercial adaptive cruise control products, two types of ACC products are available: Basic ACC system - Basic ACC systems adapt the vehicle's speed to keep it at a constant value. The automatic speed adaptation deactivates as soon as the vehicle ahead is no longer in the detection range of the radar. Variant of basic ACC system - this type has special functions, such as stop-and-go function and traffic jam assistance, but the basic principle is the same. One of the most common additional functions is preventing the vehicle from completely stopping when using the cruise control in order not to lose the set speed. Full-range ACC system with steering - this ACC feature uses both radar and camera to detect the vehicle ahead and maintain its distance (with brakes and throttle); it also has a lane-keeping function (with steering). The processing of various data, such as camera, radar, GNSS, electronic horizon map, and inertial angle is implemented by the electronic control unit. This unit sends control commands to the various actuators. GNSS signals are used to calculate the real speed. Such a system is complex and has various advantages and disadvantages depending on the features described. Some car drivers show a preference for the function. It must be noted, however, that the availability of cutting-edge devices in an international field test could explain why some users miss ACC as the test was observed mainly in China. However, a disadvantage of this feature is that one must handle the steering wheel; otherwise, the car will stop. Currently, a complete free-condition ACC system is being developed. With this system, the driver does not need to handle the steering wheel during traffic jam behavior. Note that it is not yet on the market.

3. Machine Learning Algorithms for ACC

Machine learning occupies a central place in the development of ACC, due to its ability to directly learn from data and employ predictions, classifications, and constrained heuristics derived from the data to improve control performance. The foremost data-driven learning type used in developing machine learning algorithms is supervised learning, which is used to train models with labeled data. Herein, the classification algorithms and the regression technique are all subjects of advanced and often reported real-world studies to improve vehicle control ACC performance, ADS reliability, and customer acceptance. Unsupervised learning models are more frequently used for identifying patterns from unlabeled data. Reinforcement learning is a distinct approach used with machine learning that allows the learning system to be directly trained through interactions in a dynamic environment.

A well-discussed exemplar real-world application is the use of genetic algorithms to address the issue of longitudinal control of midsized trucks. The computational demands of machine learning are a significant constraint when dealing with embedded real-time vehicle control systems. Substantial time is incurred in creating the models and training the system, as large volumes of data must be processed offline. Model predictability decays away from the feature ranges of the input data for which the models were trained. Machine learning adds support for new behaviors by changing the parameters of vehicle control models. The addition to an ACC would be more straightforward, as the technology would add minimal complexity, although the ACC would then be required to interpret different signals and human intent.

3.1. Supervised Learning

Supervised learning is one of the fundamental algorithmic methods in current vehicle adaptive cruise control (ACC) systems. In a supervised learning application, a dataset containing input-output pairs is formed to typically train an offline model. Methods to form such models are widely diverse and aim at providing algorithms that can work with a model precisely enough in the real world, while typically trading accuracy for performance requirements. Advantages of the supervised learning used in ACC include predictability, which is an important requirement in real-world scenarios. The learning process is wrapped around the model learning, while the method of learning actually represents the basic intelligent part of the model to draw any kind of analogy and association. Where the limitation is in learning boosted by model creation, the training does not have any logical boundaries to reach the best model. This section discusses a review of analysis and comparison of some supervised learning methods that are widely used for ACC, with all specific benefits and challenges.

In ACC, there are two major variants in terms of conducted main applications: regression and classification. Classification in ACC focuses more on monitoring while controlling, for multiple purposes such as situation display, alarms, safety, and security checkpoints. Regardless of the variant, several issues arise when implementing the above ACC, such as dealing with a large amount of data and the aspect of data quality, as well as a trade-off between the accuracy of the model and the overfitting of the created model, which is always important. Supervised learning is basically used in the majority of ACC works that have pursued optimization-based systems. ACCs have been developed to regulate the engine torque, throttle angle, or actuators associated with anti-lock braking systems as suggested with a fuzzy-based speed controller.

3.2. Unsupervised Learning

ACC learns the correlation of diverse label data taken from a lot of scenarios. Using the dataset accumulated in the real world, ACC could show a general driving style. However, in this manner, only adaptation to different individuals' driving styles and different speeds could not be achieved. The unsupervised learning algorithms could analyze the unlabeled data and automatically discover the underlying hidden patterns and structures of the data samples. A great many potential works in traffic analysis and traffic scenario detection could benefit from the proposed unsupervised learning-based scenario partition method. In those relevant practical applications, the scenarios conducted by diverse vehicles are various. The unsupervised learning-based method could analyze the dataset and yield the corresponding scenario database, and different scenarios are dynamically updated with the increase of the unlabeled vehicular data.

The unsupervised learning techniques include, but are not limited to, clustering and dimensionality reduction. Clustering is the organizing of objects into groups such that there is similarity between the objects of the same cluster and dissimilarity between the clusters. Dimensionality reduction is an unsupervised learning method used to reduce the number of input variables by obtaining the corresponding features that cast the most information on them and that live in a low-dimensional plane. The methods generally concatenate two steps: a feature learning step that explores the input data structure to render it in the neural network feature space, and a dimensionality reduction step. Although unsupervised learning offers an attractive approach to model autonomous agents, especially in this exploratory context, it raises new computational, performance, and behavior interpretation issues. Additionally, in machine learning research, most research articles address the specific field of traffic or vehicular prediction based on those unsupervised learned vehicular datasets.

3.3. Reinforcement Learning

Reinforcement learning (RL) is a key aspect of current research in the development of adaptive cruise control (ACC) systems. RL considers a system as an agent that interacts with an environment, which, after every action, supplies a scalar signal known as the reward or reinforcement signal to the agent. An agent aims to find a control policy that defines the action the agent takes at any state. Through the trial-and-error interactions between the agent and the environment, the aim is for the agent to learn the optimal control policy or actions that result in maximum rewards. In machine learning, decisions are not based only on input data but also on the expected reward, i.e., whether some action would lead to a better state in the future.

Recent papers propose the use of RL techniques for controlling ACC systems. A learning technique for adaptive speed regulation in connected ACC with time-varying changes in driving style is presented. A learning algorithm with a level on an autonomous vehicle is proposed for solving the lane change management (LCM) problem, which has a highly dynamic feature. RL has the potential to handle non-convex complex cost functions produced from several variables. The adaptive cruise control system is a gain-scheduling-based control system designed to react to traffic conditions. Consequently, when driving on public roads, there will be many time-varying parameters that are either unknown to the controller or are known to change with time. RL has the capability of learning the optimal control action over many operating points as it collects more data over these traffic states. RL has the capability to exhibit robustness to off-policy tests, unknown disturbances, noise, and external forces to the vehicle, since there is no direct model of the optimum to follow during training. Finally, RL has the capability to work well as an online/real-time controller continuously adjusting to the varying dynamics of the vehicle.

4. Lane Keeping Systems

Driving a vehicle relies on the ability to position the vehicle in the proper driving lane, which is necessary for safe navigation and the prevention of collisions. The recent growth in driving assistance systems in semi-automated and automated vehicles further emphasizes the significance of not deviating from the proper driving lane. To accomplish this, these advanced vehicles often rely on lane-keeping systems. Two of the predominant technologies used for lane tracking include optical sensors, such as cameras, as well as light detection and ranging systems. Monocular and stereo camera configurations serve to guide lane detection in the majority of lane detection systems. The performance of these camera-based systems depends on the control points detected and the lane tracking algorithm employed, making bending, straight, and multiple lane detection possible. Flexible and efficient object detection, such as lane detection and identification, becomes possible when LIDAR systems are used.

It is common for lane-keeping applications to operate at different control intervention levels. The most sensitive level involves lane-keeping warnings, while lane-keeping assistance systems progressively intervene in control intervention. Several works have shown that integrated control systems are more effective than individual safety systems and driver assistance systems. One of the more popular lane-keeping assist systems is a so-called Lane Departure Warning/Lane Keeping Assist system designated as LDW/LKA. When the direction indicators are not active to signal an intention to leave the smooth road, LKA controllers employ a variety of sensor solutions and may vary. Difficulties arise when dealing with poor road conditions or broken, conflicting, or faded road markings, as well as obstructions, hills, and dips. Besides promoting safety, research has suggested that such systems reduce vehicle ownership costs since property damage claims and driver injuries simultaneously decrease. Moreover, they do not necessarily require driver behavior change.

4.1. Importance of Lane Keeping

Lane keeping is the core component of Advanced Driver Assistance Systems (ADAS), especially for trade-off scenarios on highways, where the ability to provide pinpoint lane deviations plays an important role in delegating lane changing and overtaking behavior. Therefore, a lane keeping system will not only link conventionally adopted vehicles equipped with lane departure warning and lane keeping aids functions but exceed them by offering a dynamic, failsafe control valve while maintaining lane accuracy below some specific standardized threshold limits. If met, the control will feedback cushions the vehicle occupants from two effects, such as road deviations and other lane change occasions, by returning the vehicle to the safe intended driving path and then preventing it from colliding. Currently, several road safety authorities are using the lane-keeping tracking error to evaluate the overall effectiveness of their crash avoidance systems. The lane keeping system has demonstrated an increase in driving accuracy and less conflict in the driving task shared by the driver and the

ADAS vehicle. However, if a driver becomes distracted, he or she will no longer be able to control or have faith in the AI-based lane keeping feedback control system due to the expansion of automation overuse and the ability to predict the future. However, he is less likely than the driving scene to dive and less active during AI overtakes as well. Similarly, decreasing road pavement and traffic could result in decreased lane marking performance. In addition, poor weather conditions may also affect the lane offset. In conclusion, a good lane offset motive or wraparound trajectory at the right time will have a wonderful emotional souvenir for the driver. In the future, the AI-based roadway exciter will play a vital role in developing fully functional custom vehicles.

4.2. Types of Lane Keeping Systems

Passive Lane Keeping Systems: Passive lane keeping systems only provide warnings. When sensors detect a situation of concern, this information is relayed to the driver. They remain in control of steering and are responsible for taking action. The only valuable input provided to the driver is an increased situational awareness, which may improve traffic safety. Active Lane Keeping Systems: Active lane keeping systems are designed to take control of steering. When a potentially dangerous situation is detected, the system will intervene by moving the steering wheel. Corrective steering actions are performed in order to assist the driver in staying in their lane. Lane Departure Warning (LDW): The simplest type of passive lane departure prevention system is the lane departure warning. An LDW detects if the vehicle is crossing the lane marker. If this occurs, the system provides an auditory, haptic, or visual warning to the driver. Lane Keeping Assist (LKA): To enhance the system's functionality, an even smarter active lane keeping system that may automatically avoid collisions and help to pass, the LKA system provides assistance to the driver's steering control to prevent the vehicle from inadvertently leaving a detected lane. Both systems are commonly based on video sensors and various algorithms that detect lane boundaries. This ranges from simple rules that trigger the warning whenever the vehicle moves closer to the lane marker to advanced curve-fitting algorithms that are capable of determining the lane curvature and a proper steering intervention in near real-time. The latest trend of this system is the presence of deep learning methods and their possible benefits. The primary advantage of lane keeping systems compared to collision avoidance systems is that the resulting steering assist is predictive and less sensitive to the driver's reactions. This may reduce the necessity for advanced driver models that take into account expected driver interventions. Moreover, recent studies have shown that drivers' primary reaction to lateral vehicle control system interventions is in the opposite direction to the steering wheel.

5. Emergency Braking Systems

In order to improve safety, stopping the vehicle should be more powerful in case of an unexpected situation requiring sudden stopping or severe brake input. Currently, all modern vehicles employ some kinds of systems aimed at reducing the severity and effects of obstacles. Collision mitigation systems capable of preventing accidents and reducing collision severity are becoming increasingly important owing to increased vehicle safety requirements and decreasing stopping distances. Mitigation strategies could be as simple as alerting the driver about an impending collision, applying joint operation of the human and machine systems in avoiding accidents, or completely removing the human from all operations through automation.

Due to unexpected phenomena, vehicles might encounter a possible collision; some interventions should be performed to avoid or minimize the collision. Distance warning and adaptive automatic emergency braking systems Distance warning is an information system that warns the driver of the actual or soon-to-be adjustment of the vehicle's longitudinal speed. Based on the mandatory or driver input provided, the following actions may include the joined demands for engine control, cruise control, and brake supplementation, or even one of them. Automatic emergency braking could prevent road accidents by employing on-board sensors to detect hazards, such as obstacles and vehicles ahead, or figure out if there is a possible rear-end collision severe enough; vehicles will alert the driver to apply the brakes. Vehicles come pre-loaded with uninformative benefits and integrate systems. Automatic emergency braking utilizes cameras and/or radar to identify potential collisions. A high-speed microcomputer quickly calculates the distance and energy between the driver and the obstacle and implements emergency braking protocols. The strategies currently utilized are activated through hydraulics to apply the brake system's bulb or the robot control system in the event of a need. The strategies are implemented by applying brakes through engine controllers to immediately reduce power to help reduce the force and robustness of the brake. Redundant CPU units may guarantee maximum system endurance and deal with software failures. Common technologies require incorporating robust, sensor-based automatic emergency braking technologies up to and over 7.5 mph. It is possible that these systems can alert drivers to a possible collision and get the car stopped near yet clear of the obstacle to prevent further injury. Automatic emergency braking-induced injuries can be minimized at speeds greater than 7.5 mph. The technology at 15 mph is mandatory and becomes more sophisticated to deal with different types of vehicles at 25 mph.

5.1. Need for Emergency Braking Systems

Accidents occurring as a result of sudden stopping of a preceding vehicle are one of the common reasons for road traffic accidents. Brake systems are designed to prevent such accidents and are mandated in developed countries as well as emerging ones. However, braking systems are designed to work based on the information collected by drivers about the road, followed vehicles, and hazards. Human factors such as reaching out for control or the steering wheel, brake pedal reaction times, and others are some of the reasons for accidents. In recent years, segment shifting towards autonomous robotics has improved the road safety system. The most important role of an emergency braking system is to assist in hitting the brakes by mitigating the unseen hazards that the driver cannot see. Accordingly, it allows ample time for the driver to take evasive action with clear visibility. Emergency braking systems play a very significant role in the automobile scenario, and the braking system is an important part of the vehicle.

In a study, more than 250,000 vehicles are damaged due to a rear-end collision, and almost 10% of the accidents belong to the sudden emergency stopping conditions. Around 45% of the drivers take 1.7 seconds for braking, which is critically important for the rear-end braking system. Seventy-one percent of the highway accidents are attributed to human errors such as inattention, distraction, inadequate search of vehicles, illness, and exhaustion. From a legal perspective, a vehicle's brake system has to conform to the motor vehicle safety standard 124. Consumers and industry groups have also perceived the need for electronic braking technology. Consumer awareness of the advantages of electronic braking system technologies has led to a boost in the demand for advanced brake systems. The electronic brake system market is expected to result in a 5.54% CAGR increase to reach $75 billion by 2030. Emergency braking scenarios in practical conditions are numerous. A few of them are discussed in the next section. Although modern anti-lock braking systems are technically advanced and can reduce the braking distance effectively, it has been reported that head-on accidents have not been extensively reduced. These attributes point towards the possibility of enhancements in modern vehicle braking systems. The automotive industry has globally developed many of the concepts of built-in automatic braking systems to reduce head-on collisions. It works by always scanning and monitoring driver input in relation to potential danger. These technologies demonstrate the potential for further development. The need for integrating the driving and vehicle systems for improving road safety has been considered. This gives insight into probable future collaborations for improving road safety using such technology.

5.2. Components and Functionality

Components: Research into integrated vehicle controls in emergency or critical situations has entered the technology readiness level 6-7. However, there is still much industrial interest in the possibility of developing such systems, as this can lead to substantial commercial benefits. Future technologies in both the automotive and aerospace sectors should provide for integrated or closely coupled vehicle control systems in order to enhance overall performance. Systems that adjust other brake and drive systems are already in series use or at an advanced stage of development. Many of these systems offer a wide range of functionality; they may issue alerts to drivers of impending danger, apply partial braking in hazards, activate steering assistance in some cases, and take corrective action automatically if necessary.

Functionality: All emergency braking systems consist of an obstacle-detection system in combination with activation algorithms, and a brake system that will trigger to release sufficient braking of the non-prioritized wheels to initiate yaw deceleration with the vehicle on a given maneuver trajectory determined by the speed of the wheels to be braked. The obstacle detection systems combine, or use individually, sensors that measure vehicle relative speed and range of potential obstacles in the forward and lateral directions; such sensors may include forward-looking radar, forward-facing cameras, and LIDAR or other range sensors. Activation algorithms are usually based on neural networks or similar systems taking input from the sensors mentioned above and generating brake activation and longitudinal distribution of braking force between the wheels determined from lateral side-slip angles to be expected by the uncontrolled wheels when activated until friction grip is regained. Types of braking mechanisms used can vary depending on the desired performance; they might consist of hydraulic braking systems for the wheels to be braked or electronic braking systems in combination with hydraulic ABS control to achieve the desired effect. The main advantage of electronic braking/hydraulic ABS is that brake pressure can be applied to the wheels to be braked independently of the pressure to the remaining wheels, allowing maximum activation of traction control. Redundancy is always an integral part of safety-critical systems. In these systems, weak spots are replaced by having multiple elements for each primary function. This will give a performance increase under normal running and provide backups in the event of failures. Redundancy and enhanced fault tolerance are also developed for emergency braking systems; specific fault tolerance and redundancy aspects are included. These emergency braking systems are designed to be highly reliable; a 99% level is typical. In addition to the hardware and software resilience, human driver interaction is also critical. Because the systems are active, the driver can always override the automated action. If it is felt to be necessary, the driver can brake using skills that are boosted by aids. The project completed successful experimental validation of an independently controlled vehicle version. Although case studies are not often used in projects, information on operational validation can be found. This describes a practical application. Obstacle and vehicle trajectory models are presented, and the process of scenario construction is illustrated. It then describes the implementation of the braking algorithm for a braking group of the system. Brake and vehicle model parameters, including wheel-to-seat data, are shown. Braking performance is validated and presented experimentally.

6. Future Direction

Regardless of the AI techniques employed, the design and performance of vehicle control systems are expected to be dramatically reshaped by emerging vehicle technologies in the near future. The past two decades have seen a gradual shift from human-centered driving systems to increasingly automated driving. Regulators predict that a significant percentage of new vehicles on the road will become highly or fully automated over the next decade. Thus, automotive manufacturers are creating AI systems to endow vehicles with driving characteristics and behaviors that are increasingly human-like. There are four major technological trends that are reshaping the development of AI-based vehicle control solutions: automation and driver monitoring; artificial intelligence, machine learning, and data integration; communication technologies; and sensing technologies using advanced lidars, radars, and images.

This new future offers several new research directions. The performance of AI algorithms is expected to continue to improve rapidly, particularly as researchers devise machine learning algorithms that can effectively integrate data from vehicles and from traffic control systems. AI methods that optimally integrate the vehicle-level and intersection-level data that become available may result in significant new systems for achieving interconnected and automated traffic control solutions. Furthermore, the new generation of AI vehicle control systems will have to be secure to be acceptable to the general public and to policymakers. As AI methods become more integrated into vehicle interconnection and automation technologies, end users and the regulatory process have increased influence on designing the specifics of performance objectives and logical constraints controlling these new vehicles and the systems in which they operate. There are also other issues to be resolved regarding ethics, equity, and policy, and there are many open challenges in cybersecurity. As vehicles become increasingly automated, it becomes increasingly difficult for regulators in the industry to sort through the implications of allowing individual automakers to set their own performance targets. The role of regulatory and industry standards in defining vehicle performance is not mentioned, even though it also constrains many future directions. Comprehensive vehicle system design requires model-based prediction of environmental interactions, some of which are currently not well understood. The existing work revised the future direction by updating the regulatory framework and the industry standards for vehicles and discussing what end users expect. Because AI models for intelligent vehicle control systems are already part of a society-scale system of AI models, AI models designed for vehicle dynamic controls must be interoperable with other systems that automakers or others integrate into their vehicles. The model will not be designed in isolation, as was the case in the past. The systems in which AI models are embedded will expand to include AI models concerned with innumerable features of the AI grid.

7. Conclusion

In this project, we explore how AI techniques have been used to increase the target space that current and future active vehicle control systems can handle effectively. In particular, we have focused on the areas of vehicle stabilization and safety. The rumble strip detection system described is an important and innovative application in which the benefits of directly using AI to complete the control problem are very apparent. However, being able to develop and use control systems and driving aids only with real-time restrictions has significant benefits. Being able to make any aspect of an active vehicle control system adaptive to changing driving, road, or vehicle conditions would be inherently beneficial, but is often not possible to do in real-time. Adopting an AI-based approach, we have shown that acceptable and potentially high levels of performance are possible. In the future, as computers, sensors, and software continue to advance, we can also expect that the performance of these systems will continue to increase.

In summary, although most of the examples we provide are still experimental systems, the enabling technology is advancing in leaps and bounds. As computer hardware and software continue to advance, we will be able to depend more and more on this technology to increase the performance of these systems. Moreover, as the functionality of active safety and driver aids in today's vehicles continues to increase, the real applications for the detection systems we describe here will also greatly increase. Again, because of the tight real-time performance constraints that apply to the detection functions for robust operation of actuation systems, the balance of performance, complexity, and implementation constraints still makes AI a particularly appropriate approach. In conclusion, although the real-time computing capability required currently limits the application space for some of these types of systems, for others, particularly driving aids, these AI-based systems already provide the necessary real-time detection.

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