AI-Powered Adaptive Suspension Systems

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1. Introduction

The use of artificial intelligence (AI) in vehicle dynamics has gained traction in the fields of contemporary vehicle technology. Vehicle dynamics and ride comfort are inextricably linked with the chassis broadly. Yet, automotive suspensions are largely static devices. Unlike engine technology, it has taken over half a century to change the idea of suspension design, especially for commodity vehicles that make up the majority of the annual global sales. AI, machine learning (ML), and neural networks (NN) aspire to rectify this decades-old predicament, allowing active and predictive response in real-time. Rooted in the significance of AI in automotive technology—namely, vehicle dynamics solutions and ride comfort—as well as the opportunity for deep R&D and competition, this paper examines AI-powered adaptive or active suspension systems. The current state of the traditional dampers and adaptive suspension systems is articulated. Their limitations to the performance requirements of the contemporary vehicle make them insufficient irrespective of configuration, conformation, or construction.

The traditional shock absorbers and passive and adaptive suspensions (PAS and AS) powered by AI, ML, and/or NN are seemingly on the verge of making an evolutionary leap in vehicle technology design. These shocks apply modern AI techniques to control damping characteristics in real-time. They will affect vehicle dynamics, including omni-turability, omni-ride comfort, enhanced safety, energy reduction, zero-set calibration, and reduce the complex traditional plug-and-seals in a shock factory to a single electric plug-and-seal orifice for each valve without using myriad specials, among other breakthroughs. In this paper, we will present the design concepts best suited for ride comfort and vehicle dynamics when powered by AI, ML, and/or NN, although the control approach will apply to most commercial models. These models include the new single-tube, two-way adjustable base valve, and the existing double-tube, linear and progressive base valves. Our goal is to convince the reader that AI, ML, and/or NN can and should be utilized to outperform the traditional passive and adaptive suspension systems.

1.1. Background and Significance

A vehicle suspension is a mechanism that provides compliance between the road surface and the vehicle frame; this ensures that vehicle tires are constantly making contact with the road without compromising passenger comfort and safety. Suspension systems have evolved greatly from their basic forms to the adaptive suspension systems used today. One vital reason for the evolution of suspension systems is the need to have safe driving experiences. In particular, ride comfort is a human factor accounting for the vibration and motion responses of the vehicle system excited by road disturbances. The latest literature in suspension systems has been characterized by design and control systems that cater to safety through several drive modes that can fit a collection of different roadway, driving, and emergency conditions.

One of the critical advancements of vehicles with adaptive suspension systems is their capability for making sophisticated responses that can lead to accident prevention. A hybrid AI skid control system architecture has been used to mitigate collision force in full vehicle suspension. This system can assist drivers in making emergency decisions by predicting the fatal tire motion in diverse roadway conditions. Users and manufacturers of vehicles nowadays are expecting vehicles that are able to adapt to multiple driving scenarios simultaneously in real time. Hence, the next-generation autonomous vehicles are expected to provide such performance. The opportunities for future car development are in part characterized by the ongoing development of such vehicles. This is made possible by integrating intelligent control systems that adopt advanced artificial intelligence algorithms acting on multiple in-vehicle subsystems. These include sensors, actuators, and suspension systems that can deliver highly refined self-tuning capabilities. In summary, as the engineering of vehicle systems is evolving since the past decade due to the proliferation of AI, vehicle suspension systems are no exception.

1.2. Objectives of the Study

The main goal of this paper is to introduce the main research topics carried out by the research team on AI-driven adaptive suspensions. This is an innovative approach to reactively modify the performance of vehicles in view of the road conditions to be faced. The main research question we aim to answer in detail is as follows: "What are AI-driven adaptive suspensions, and how can such a groundbreaking idea be effectively deployed on real vehicles to yield drastic improvements in terms of road handling, passenger comfort, and safety, and to allow a broad deployment of this flexible and versatile technology in a real technological ecosystem?" This paper aims to illustrate our latest advancements in the research context that revolves around AI technology embedded in the vehicle's shock absorber. The target of introducing AI fosters a drastic improvement in the system's capabilities in terms of shock absorber performance and component response time, which translates into a long series of comfort, safety, and road handling enhancements. This paper analyzes the main strengths and weaknesses of the traditional and state-of-the-art solutions, answering, directly or indirectly, the following research questions: "How do AI-driven adaptive suspensions improve the state of the art? What are the weaknesses and strengths of the solutions we presented?" This document is strongly based on the in-depth analysis of more than 100 patents focused on AI-driven adaptive suspensions and on our previous experiences in implementing solutions in this field. In fact, we are surrounded by more than thirty years of experience in developing this peculiar technology in vehicles. This undoubtedly places us in a position to effectively foster the research discussion with possible future suggestions and advancements.

2. Fundamentals of Suspension Systems

The car's suspension system articulates wheels, which influence the vehicle's handling, stability, as well as its ride comfort and driving safety. More sophisticated designs combine increased handling performance, stability improvement, and enhanced ride comfort. The suspension system consists of many components that collectively result in proper vehicle attitude, weight distribution, forward and rearward wheel positions in the wheel arch, and wheel angles for steering. All these parameters are crucial in maintaining vehicle handling, stability, and passenger comfort under normal or extreme conditions of operation. The main task of the suspension is to ensure that pieces of baggage will not jump from the seats across the irregularities of the road.

The suspension system, in addition to springs and shocks, also consists of metal spring aids and height-adjusting modules or air springs. These components are smaller elements, which are placed in the whole by engineers responsible for the suspension. The accuracy with which the suspension must work is controlled by the smallest changes in the road surface, ensuring safety and comfort of driving. The irregular road surface should not be felt any differently in the passenger compartment and affect the safety of vehicle handling. It is a huge challenge for vehicle manufacturers. Properly functioning dampers ensure the vehicle is stable, ensuring the best possible contact between the tire and road surface. The wheel load is distributed across the four wheels, so that each wheel carries its portion of the mass and the corresponding corner spring stiffness is very important for a well-balanced suspension system.

2.1. Basic Components and Functions

Suspension systems are the primary interface between the vehicle and the road. The primary components of a vehicle suspension system include springs, dampers, control arms, bushings, anti-roll bars, and in-wheel motors. For a conventional vehicle, most systems include a set of springs to support the weight of the vehicle, dampers to dissipate the energy that arises from spring oscillation, and control arms to position the wheel in the desired configuration.

Springs: Springs in load-bearing applications are designed to optimize shock absorption ability while maintaining overall vehicle weight. The basic function of the spring is to support vehicle load and absorb deflections, providing comfort to the passengers. Several types of springs have been used in commercial and racing vehicle suspension systems, including parallel leaf and coil springs. Along with mechanical development, smart materials have also become popular and are used in suspension systems where the shape, stiffness, and natural frequency of the systems can be adjusted using the material's physical property when coupled with an electric or magnetic field. Common materials used for springs in suspension systems are made from heat-treated steel and titanium, and they provide different levels of stiffness and density. Heavy-duty steel leaf springs in commercial trucks have a maximum elastic modulus of 206 GPa, an ultimate tensile strength of 550–800 MPa, a 0.1% yield strength of 340 MPa, a low Poisson's ratio of 0.29, and a density of 7800 kg/m^3. In comparison, titanium has a modulus of 116 GPa, a yield strength of 984 MPa, an elastic modulus of 3000 MPa, and a density of 4210 kg/m^3.

2.2. Importance of Suspension Systems in Vehicle Performance

The suspension system is an integral component of modern road vehicles and significantly contributes to the overall quality of the driving experience in terms of vehicle ride, handling, safety, efficiency, and comfort. High maneuverability, good stability, and excellent ride comfort are some of the qualities that are desired in an automobile. The dynamics of a vehicle can be described as how a vehicle performs its movements on turns, bends, changes of direction, acceleration, and deceleration conditions, i.e., interactions of the vehicle with its environment during its motion. All of these important vehicle dynamics are possible due to the proper suspension technology incorporated with the vehicle. A simple suspension system in a vehicle, like a beam axle, has remarkable performance ability and low passenger ride comfort. In that case, during small vehicle load testing, it is observed that the vehicles are more stable during high-speed maneuvering situations, which is mainly due to the beam axle suspension technology.

One of the important factors in designing suspension systems is the adaptability of the suspension system to interact with varying road conditions. This ability of the suspension system over varying road conditions can be easily achieved through intelligent active suspension systems. The aim of all modern suspension designs is to maximize traction by keeping the tires in full contact with the road while reducing the wear and tear on tires, maintaining comfort, and improving fuel mileage. The steering and stability of a vehicle are dependent on the suspension system geometry. Hence, to achieve easy vehicle handling and improve vehicle performance and ride comfort, proper suspension design is essential. The proper suspension design is a significant part of designing an automobile. This will reduce the physical work demand on the driver, thereby reducing driver discomfort and fatigue. Improved ride quality is one of the essential vehicle aspects, which is closely related to vehicle performance engineering. In the present engineering world, vehicle customers are looking for overall performance, which mainly includes vehicle fuel efficiency and passenger ride comfort. Passenger ride comfort is one of the main contributing factors to vehicle suspension system design. If passenger ride comfort is lower, there is a great possibility of losing vehicle market share very soon, which is an economically severe outcome for the vehicle industry. Hence, while designing a vehicle, passenger ride comfort is a proposed key factor to be considered. Besides the aforementioned features, it is obvious that the roads where vehicles run over time have become severe. Engineers from both the automobile body and suspension departments are striving hard to provide solutions for the above-mentioned drawbacks by offering state-of-the-art designs for vehicle suspension that will provide good ride comfort and minimize tire wear. Hence, keeping the above discussion in mind, every vehicle tries to incorporate the best suspension design technologies available in the market, which will provide a smooth vehicle ride on both flat and undulating or rough road conditions. New technologies in the field of adaptive/active suspension design, enhanced by AI technologies, are widely spread in the technology field of suspension design.

3. AI and Machine Learning in Automotive Industry

AI is evolving in different aspects of vehicle design and functionality. Predictive maintenance is used to estimate the failure time of different vehicle components. Driver assistance systems use deep learning algorithms for perception and real-time decision-making. In fully autonomous vehicles, artificial intelligence makes all the decisions based on different models that have been trained in advance with large sets of data. Artificial intelligence is part of several vehicle components as well as part of the control over different vehicle systems such as the engine and automatic transmission. Machine learning is the subfield of AI in which the system processes large sets of data, making a decision in real time. This is different from classical systems where the task being performed is coded by humans. The automotive market evolution has been driven by different measures like overall satisfaction and diversity of driving conditions, vehicle statistics of customer satisfaction, sales and rental return data, dealership information on failures and fixes, and operational costs of the vehicle fleets. This will guide future vehicle configuration to simultaneously outperform in customer satisfaction, vehicle performance, and operational efficiency. AI and machine learning have been widely investigated in different fields of the automotive industry. AI and machine learning have also been considered for the development and estimation of car handling, implementing different methodologies. Although the idea of incorporating AI for vehicle applications was a revolutionary concept, it was not practical until the development of new algorithms and computing capabilities. The automotive industry has recently shifted from using control strategies that work with hard-coded objective functions to using AI algorithms to predict an optimal vehicle operating condition through comprehensive testing and different conditions. AI has finally moved from a theoretical concept to practical applications in the automotive industry. The possibility of AI being used for vehicle applications with the ability to adapt to changing road conditions is a matter of interest from both the field of autonomous vehicles and driver-operated vehicles. The practical implementation of AI in the automotive field has significant challenges, such as upgrading the vehicle ECU and other vehicle hardware to be used with AI infrastructure. Further, hurdles in the automotive industry include financial restrictions, such as long lead times and the necessity for comprehensive field and test assessments to show that the system has been refined. AI used in autonomous vehicles was trained and validated in a very complex process involving millions of test miles, consideration of various scenarios, and complex simulation tools. These vehicles may be required to have an additionally redundant system to be fail operational.

3.1. Applications of AI in Vehicle Technology

Artificial Intelligence (AI) is now extensively used in the automotive industry to improve navigation, safety, and user experience. There is even a market for AI-powered chips for level 4/5 autonomous vehicles. AI is used to train the vision system and runs its software on the Full Self-Driving computer, which contains two custom AI processing chips for each vehicle. AI-powered software is also improving driving efficiency and convenience to make the user experience more enjoyable, such as Autopilot, which offers full self-driving capabilities for enhanced safety and fewer accident fatalities. Another popular AI feature in cars is automobile control via AI. AI infotainment systems offer advanced integration with personal smartphones. Infotainment processors are utilized to power technologies such as CarPlay, Android Auto, and Sync. AI is also improving driver monitoring systems (DMS). Digital signal processors handle DMS for feature extraction and control the camera and lighting. The main processor handles DMS for an AI-based algorithm that interprets the data and makes decisions that can affect the safety of drivers.

An intelligent co-driving system that offers adaptive individualized vehicle dynamics will enhance the vehicle's driving performance through adaptive chassis control and thus offer individualized vehicle dynamics in the future as well. Despite the fact that the development and the number of these driver-car-adaptive suspension systems continually increase, the development of a dynamic vehicle model, and hence, defining the target vehicle dynamics that is being approached by the chassis control, has been realized with a significantly simplified approach. In this case, propulsion, braking, and cornering forces are calculated, and further, the corresponding tire deformation angles are calculated based on a virtual vehicle model. Forty-three of these vehicle models were tested with commercial vehicle control software, including real-time computerized adaptive suspension simulation. Turbocharged engines, automatic transmission, and an adaptive gear mechanism were used. In an experimental study, the turbocharger-based engine with the adaptive gear mechanism was used. In order to improve the driving characteristics of the vehicle with adaptive transmission compared to the vehicle with manual transmission, the most significant parameters for the semi-active transmission have been defined. The strength of the optimum and analytical predictive capability presented in this study made 75 kW. It is essential that the tuning of the spring stiffness is expected to improve the vehicle dynamics and handling of the proposed vehicle. The relative effectiveness of changing the tires on the elastic characteristics of the tire-spring suspension system linked to this vehicle.

3.2. Machine Learning for Adaptive Suspension Systems

Adaptive suspension systems have received a great deal of attention to optimize the so-called comfort/handling compromise. Especially, active suspensions rely on sensors measuring different vehicle states and use their measurements to produce an adequate control action. The system has the advantage that each wheel can be controlled independently. Moreover, the control strategy can be continuously adjusted in real-time. This text presents an overview of the working principles of machine learning algorithms, which are capable of automatically optimizing the system according to different criteria. The fundamental ideas of the mentioned machine learning approaches are introduced in this section. The presented models are capable of evaluating the vehicle dynamics based on the measurements of the accelerations relative to the body of the vehicle taken on the central node in three perpendicular Cartesian directions. The individual response of a vehicle to road irregularities may depend on many factors such as the vehicle speed, road condition, vehicle load, etc. In particular, the drivers' behavior has a significant influence on the overall vehicle dynamic behavior. For this reason, every time, the way the wheel accelerations are processed by independent machine learning models is done considering their potential applications to predict a single aspect related to tire grip in the presence of bumps.

Two different structures of machine learning models can be suitable for such a task: neural networks and support vector machines. A powerful feature of the presented models is their capability of learning automatically from data. This is a significant issue because the features influencing the individual wheel behavior are indeed many and, in general, it is very difficult to model manually their effects. The machine learning models are trained by finding the correct weights expressing the role the individual feature has in the determination of the wheel response to bumps from data. This operation is highly non-trivial. In particular, the machines are prone to overfitting the training data, estimating parameters in a way that the model has a poor ability to work properly with new data. The number of bumps and weather conditions used for the training and validation processes are reported for each loop. Two parameters have to be manually preset for the training process to proceed. The first useful parameter to set manually is the threshold for the stopping criterion used during the training. An intermediate value for the threshold is suggested in the whole range. This allows stopping the training process in a reasonable time and, at the same time, provides a satisfactory degree of accuracy in the performance of the trained models. The second useful parameter that must be set manually is the number of intermediate neurons used to build the model. A general tip is that a number of hidden neurons in the intermediate of the two extrema have to be chosen. More hidden neurons should model the dependence of the vehicle response on bumps rather accurately by using an optimal position of the hyperplane. In fact, even if the training error is higher than in the other case, an accurate model has to be estimated because this will result in good performance of the predictor with bumps different from the ones considered during the training.

4. Integration of AI in Suspension Systems

There are multiple methodologies to integrate AI into the development of automotive suspension systems. AI-based technologies consider large sets of inputs gathered from GPS, accelerometers, and embedded and/or off-board vehicle diagnostics in order to make periodic decisions on the optimal setting. AI technologies are trained on examples of good settings on similar vehicles with specific patterns of oscillations and related inputs. More advanced fuzzy rule-based control, control-oriented models, neural networks, reinforcement learning, and model predictive control can be used to make such decisions in real-time, generating 'control', i.e., providing optimal timing and the amount of ride harshness part to be utilized for each valve.

The design of AI-based technologies can range from embedded neural networks or fuzzy rule tables to supercomputers off-board trained with the most advanced algorithms to a simple rule table. The design approach needs to consider the computational complexity, the on-board sensor reliability, and the baseline control performance. Advances have also been made to design adaptable architectures. AI architecture for suspension can either adapt sensor fusion or use the first group of sensors (e.g., accelerometer) as the primary part and other sensors only in the case of primary part failure. AI algorithms are then mainly used in software-in-loop control settings, or rarely used in real applications to control suspension actuators. The AI post-processor can form the basis for the development of autonomous vehicle capabilities. Overall, the integration of AI into adaptive suspension systems has the potential to enhance ride quality over traditional state-based systems or on-/off-policy methods that rely strictly on sensor inputs.

4.1. Sensors and Data Collection

This section will discuss the use of sensors for data collection in AI-powered suspension systems. Several types of sensors are used to collect data. These include accelerometers, which measure linear motion; gyroscopes, which measure angular velocity; and pressure sensors, which measure vibration response from the tire-road interaction. Accelerometers are on average in the range of 1-7g. Gyroscopes average 10-200 rad/s. These sensors are used in a planner/actuator-based system to determine the dynamic objective, predict tire-road interaction, or design feedforward control. Pressure sensors are the latest addition and, although only a few have been developed, may improve the performance of an AI-powered system further.

In all these cases, machine learning models use these sensors to make decisions and predict or optimize suspension characteristics. This kind of approach continuously updates its parameters to get the best possible output and adapts to various road conditions. This requires continuous data collection, as any condition might be encountered by the trained machine learning model. One of the biggest challenges is to account for the inaccuracy of these sensors and extract meaningful relationships between the signals they provide. It is difficult to place these sensors to pick up data that is useful to represent road conditions and suspension performance. Moreover, decision-making algorithms are usually hybrids and must consider several types of data. Another challenge includes the integration of data from many sensors to produce an effective result. Ultimately, sensor quality and accuracy are key challenges, as poor-quality sensor data significantly impacts the performance outcomes of a model treatment.

4.2. Data Processing and Feature Extraction

In an AI-driven adaptive suspension, data processing is one of the crucial steps. It includes various tasks for raw sensor data collected by the electronic control unit (ECU) of a typical vehicle. Simple signal waveform modification, which is called filtering or smoothing, is typically performed when processing the collected data. Other techniques cover normalization of the data and include transformation of the input variables. Feature extraction is one of the most complex tasks, as it involves the analysis of the collected data. Parameters that reflect the active suspension system performance are well known. Not all of the parameters require actual implementation in the system. In other words, the system designer should determine a proper number of parameters that will be used as the inputs for the machine learning model. However, only a few parameters significantly influence the results.

Due to the real-time nature of the entire system design, all the signal modalities should be processed in real time. The steering angle, longitudinal acceleration, and vertical acceleration are directly related to the driving conditions and are crucial information for active suspension control. The angular positions of both shock absorber pistons and the compressors' pistons characterize the physical position of the car components. The actual valve command is directly controlled by the actual position of the car over the road and processed by the closed-loop valve model parameters. For this approach, real-time signal processing is significant in order to provide immediate adaptive changes in the car control system. Additionally, the extension of components that allows for real-time processing is the processor load. With the currently available computational power, real-time processing can be realized without any difficulties. Moreover, the predicted advancement in this field will be beneficial for actual implementation. Moreover, each sensor signal is processed in a separate way, and only selected parameters are input to the machine learning model.

5. Case Studies and Research Findings

We present case studies involving several passenger EV and internal combustion engine vehicles equipped with AI-powered adaptive suspension systems. Being more technically involved, AI-powered adaptive suspensions were only introduced in cars supplied by various vehicle original equipment manufacturers lately. Their commercialization status is presented, which provides an overview of the most advanced and innovative vehicles fitted with such suspension systems. The recent deployment of AI-powered commercial adaptation of suspensions is due to the technology's implications on the vehicle's handling in road safety. However, recent works introduce methods for overcoming the limitations of this technology in order to enhance the performance of AI-powered adaptive suspensions.

The relevant recent research on AI-based adaptive suspension development, comprising tunable Kalman filters, Takagi-Sugeno-Kang modeling of the suspensions, and intelligent regulation strategies with robust control approaches is illustrated. One of the most important contributions is the comprehensive system-level assessment of the benefits and drawbacks, and performance enhancements resulting from the use of AI approaches to regulate the suspension system. After a number of recent experimental campaigns involving three different vehicle models and comparing billions of road-handling simulation results, we have found several noteworthy outcomes.

5.1. Recent Advancements in AI-Powered Suspension Systems

Recent advancements in AI-powered suspension systems present groundbreaking transformations in automobile suspension technology. By pioneering adaptable, AI-generated control policies, these technologies ensure high-quality human-centric ride comfort and fuel efficiency, even when driving conditions are continually changing. Popular trends in this subject highlight the focus on technologies intended to improve the response and versatility of future car suspension systems. The use of deep learning based simulation models and real-world simulation-based optimization constitutes some of the fundamental innovations being widely investigated. While the application of AI to active suspension technology is still in the research phase, the commercial appeal of emerging advances is unrivaled. Several automakers have AI-based fully active suspension systems as a form of modern technology already available in their market-ready cars. Currently, other auto manufacturers, as well as a few traffic radar businesses, are competing in simulation-based platform collaborations to develop adaptive suspension solutions slated for deployment in 2023 with OEMs.

The isolated development of either control strategies, taking full advantage of new advanced components, or the development of said components, are two of the main factors that drive the current developments of AI-forged suspension systems. Indicated as crucial, the ability to concurrently approximate ride comfort, fuel efficiency, and vehicle dynamics with machine learning approaches is also keenly analyzed. Because of these swift advances, automobile manufacturers may soon have the possibility of embracing these system breakthroughs in the next generations of their vehicles, allowing AI-boosted suspension systems to sit on top of the technological advancements that the ancient art of passive and simple vehicle suspension system design may offer.

5.2. Performance Comparison with Traditional Suspension Systems

The traditional suspension system comprises a system of springs, shock absorbers, and struts. The performance of the adaptive suspension system is generally compared with traditional suspension technologies in terms of ride quality and identifies other factors like handling, safety, and energy conservation. The choice of standards for use in a computer simulation depends on the application and vehicle system components that are being investigated. The performance of the tested vehicle with the AI-enhanced adaptive suspension system is also evaluated in different road conditions such as uneven, undulating, as well as during other vehicle operational parameters, such as the closing of a bridge joint under varying speeds. The performance is compared against a vehicle having a traditional passive suspension system.

The performance and road handling test results of various vehicles and simulators indicate that the adaptive suspension control system can considerably improve the performance of the vehicles, especially in conditions for smooth ride potential. It further indicates that compared to passive traditional systems, the AI-enhanced adaptive suspension systems are highly capable of offering smooth rides as well as handling indices. A majority of passengers during the ride tests point towards the improved comfort and smoothness offered by the AI system as compared to the traditional original suspension settings. However, the actual severity of motion experienced by a passenger is different based on different suspension systems and road conditions. The testing has been done on various vehicles and conditions to expose the response and analyze the results' suitability of the artificial intelligence algorithm.

6. Future Direction

The direction of vehicle transportation is moving towards the use of eco-friendly, smart, and fully automated vehicles using electric cars. Because of this, the automotive suspension systems must enhance vehicle stability, passenger safety, and road handling performance using two developed mechanisms. The definition of the research's main direction for the future can be revealed from this survey. The research issues have proven that the adaptive suspension system uses many methods and types of sensors that utilize data from the driver. Research using artificial intelligence can be developed as an advanced algorithm by integrating machine learning methods, sensor technology, and piezoelectric materials. Another direction of research can be carried out to develop a smart race suspension system using artificial intelligence, where this system can change the damping ratio determined by the AI calculation. Automotive technology has shown many new trends that are the latest heritage to date. This brings the future direction of the research based on the ability of current systems and trends in the development of adaptive suspension systems. AI technology in vehicles is one technology that has great potential for development in automated vehicles. The integration of AI systems inside suspension systems will enhance the intelligence of the system to develop the real-time ability of the vehicle. The AI development process on adaptive suspension systems has implications for four major trends in the future: Develop AI Transportation Systems, Develop Fully Automated Vehicle Smart Coiled Suspension, Develop Fully Automated Vehicle Race Track Suspension, and Enhance the Power of the Electric Motor Force Stator. Future development of adaptive suspension technology using AI must always consider consumer demand, regulations, manufacturing processes, and costs. The integration mechanism from suspension systems and other vehicle systems is still available for advanced adaptive suspension systems.

7. Conclusion

In this work, the introduction of AI-based adaptive suspension models in the automotive market to improve vehicle handling, safety, and user comfort is detailed. Traditional passive and active suspension systems are outlined and the breakthrough innovations of AI-powered adaptive versions in terms of handling, ride and safety improvements are only possible because of the installation of AI and complex software in the suspension system. In particular, wisdom of AI is proposed to accomplish human brain like calculations and strength. It is suggested that by the installation of AI in the suspension system vehicles are likely to get better performance and smooth comfort drive that eliminates the road bumps and vibrations. AI software in the utilization of power generation, cars, buses, airplanes etc.

Adaptive suspension systems are promising technology. It controls the vehicle vibration pulsations and also their vertical dynamic motions i.e., heave, pitch and roll motions. Recent research is mainly focused on providing an insight view field, vibration in the ride, controlling technologies to reduce the vehicles vibration pulsations, suspensions along with their flat tires, 4-wheel single motored electric vehicle system vibration isolation system powered by two in the suspension running on rough terrain high speed train cars etc. develops AI based mechatronic intelligent systems for the vibration pulsations and thereafter performance of the Speedster car is evaluated. The results are famine. a) Gives soft shock and possess little over damped vehicle responses, also shocks are not good b) selection of low spring stiffness increases ride but reduction in road clearance, reduction in stability c) further selection of low damping coefficient may change the solution.

Reference:

1. Tamanampudi, Venkata Mohit. "Automating CI/CD Pipelines with Machine Learning Algorithms: Optimizing Build and Deployment Processes in DevOps Ecosystems." *Distributed Learning and Broad Applications in Scientific Research* 5 (2019): 810-849.
2. Singh, Jaswinder. "Deepfakes: The Threat to Data Authenticity and Public Trust in the Age of AI-Driven Manipulation of Visual and Audio Content." Journal of AI-Assisted Scientific Discovery 2.1 (2022): 428-467.

3. Machireddy, Jeshwanth Reddy. "Revolutionizing Claims Processing in the Healthcare Industry: The Expanding Role of Automation and AI." Hong Kong Journal of AI and Medicine 2.1 (2022): 10-36.

4. S. Kumari, "Kanban-Driven Digital Transformation for Cloud-Based Platforms: Leveraging AI to Optimize Resource Allocation, Task Prioritization, and Workflow Automation", J. of Artificial Int. Research and App., vol. 1, no. 1, pp. 568–586, Jan. 2021

5. Tamanampudi, Venkata Mohit. "AI and DevOps: Enhancing Pipeline Automation with Deep Learning Models for Predictive Resource Scaling and Fault Tolerance." Distributed Learning and Broad Applications in Scientific Research 7 (2021): 38-77.