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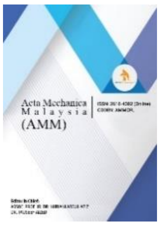

REVIEW ARTICLE

PISTON BASED LONG PULSE SHOCK ABSORPTION

K. Nikhilesh Vaibhav

Department of Artificial Intelligence, Amrita Vishwa Vidyapeetham
****Corresponding Author Email: warmvaibhav@gmail.com***

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ABSTRACT

This paper presents a novel approach to dynamically adjust the position of a vehicle platform utilizing IoT sensors and solenoid valve-controlled gas piston chambers. The system aims to maintain the platform's horizontal orientation while navigating uneven terrains, such as speed breakers. The IoT sensors accurately measure the platform's height relative to the ground and this height information is then transmitted to the solenoid valves, which regulate the pressure within the gas piston chambers. The proposed system demonstrates promising results in maintaining platform stability and increase the ride comfort during real-world road conditions. Though the focus shall be on only one model, other models will also be discussed. In addition, a mathematical model for controlling the air flow across the piston system is developed, which can be used to open and close the valve to raise or lower the piston to maintain the desired orientation of the vehicle. The proposed system has the potential to enhance ride comfort and safety in vehicles, and future research could focus on the development of adaptive suspension systems that can automatically adjust to different driving conditions.

KEYWORDS

Dynamic Shock Absorber, IoT Sensors, Solenoid Valves, Gas Piston Chambers, Ride Comfort, Active Suspension, Mathematical Modelling

1. INTRODUCTION

The suspension system in automotive mechatronics plays a crucial role in providing comfort by mitigating vibrations and bumps. Traditional suspension systems consist of mechanical linkages, springs, and dampers (Automotive Mechatronics, 2004; Runge, 2001). However, advancements in mechatronics have led to the integration of complex electronics with mechanical components, revolutionizing suspension technology (Schöner, 2004; Tomizuka, 2000; Straky et al., 2001).

Active suspension systems highlight the significance of combining integrated electronics with advanced information processing for improved performance. These systems utilize programmable control panels connected to height sensors and airbags, ensuring optimal vehicle height, wheel alignment, and grip (Automotive Mechatronics, 2004; Schöner, 2004). Additionally, they effectively absorb shocks and vibrations, with the spring and tire handling high-frequency shocks from rough terrains and the compression chamber and piston addressing low-frequency shocks such as those encountered from speed bumps (Tomizuka, 2000; Straky et al., 2001).

Ongoing research in mechatronics, as demonstrated by the cited papers, continues to drive advancements in suspension systems, enhancing ride comfort and safety. For example, recent research has focused on the development of adaptive suspension systems that can automatically adjust to different driving conditions (e.g., road surface, speed, and load). These systems have the potential to provide even greater levels of comfort and safety than traditional active suspension systems. There is a constant effort in the research community to upgrade the comfort available in vehicles. In the present paper an attempt is being made to separate the shocks into high frequency and low frequency and use two different devices to accomplish this task seamlessly, this way it becomes easy to implement in real time systems like cars to improve the user experience further.

A new piston system with double set of valves is proposed.

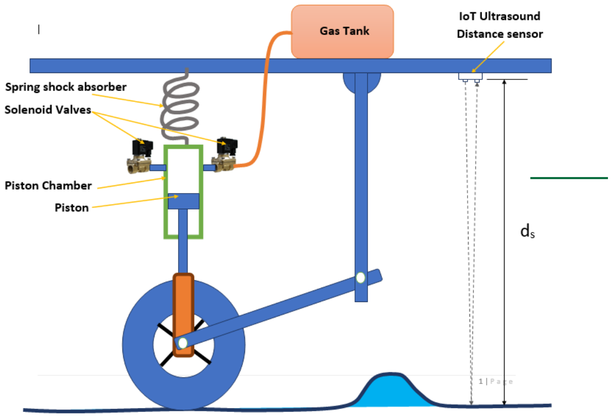

Figure 1: IoT sensor based Dynamic Shock Absorber (DSA)

A dynamic shock absorber, shown in figure 1, is an apparatus which has been designed to enhance the performance of vehicles by reducing the impact felt by the passengers and the various internal components when in contact with structures slightly elevated from the flat surface. Unlike static shock absorbers, the dynamic shock absorber can be programmed to respond to the hurdles on the road. These shock absorbers can keep the vehicle horizontal (without a tilt) even when the roads are uneven.

The present dynamic shock absorber (DSA) uses IoT sensor to determine the location of the tire in real time. If the tire either rises or lowers due to uneven road surface then the IoT sensor will be able to detect it and the solenoid valves are opened or closed to adjust the pressure in the piston chamber. This pressure will help raise or lower the tire with respect to the

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platform / vehicle. The Dynamic shock absorber responds to the uneven road by actively sensing it. Regular shock absorbers lack any kind of feedback mechanism and there is no way to adjust them based on the non-uniformity of road.

The DSA uses IoT sensors to detect the position of tires, the solenoid valves shown in the figure control the pressure inside the gas chamber and the piston is either lowered or raised based on the feedback received from the IoT sensors. Imagine the tire in the figure above encountering a speed breaker. The tire would first rise and this would decrease the distance between the wheel and the platform. The IoT sensor that is mounted on a platform can detect this change using the ultrasonic pulses. Since the pressure inside the piston chamber would rise, the solenoid valve 1 one the left would be opened, this would decrease the pressure inside the piston chamber and allow the piston to collapse. This way the tire rising on the speed breaker will not push the platform, instead it will push out the air within the piston chamber. Once the wheel is over the speed breaker, the distance between the tire and the platform will begin to increase. This increase in distance will be sensed by the IoT sensor and this time the solenoid 1 will be closed and the solenoid 2 will be opened to increase the pressure inside the piston chamber. This way the piston will be pushed downwards to compensate the increase in the distance between the platform and the tire. Essentially by maintaining the appropriate pressure inside the piston chamber one could maintain the correct height of the piston and therefore the spacing of the wheel from the road. This will result in complete compensation of the road hurdles and therefore a complete elimination of the bumps felt by the user on the platform.

In the subsequent section a mathematical model is developed that can be used to analyse the response of the system to different terrains and input forces. This mathematical model allows one to study the interaction between the spring, damping system, piston, and wheel, thus providing insights into the system's ability to absorb shocks and vibrations.

2. MATHEMATICAL MODEL OF THE DSA

Consider the following variables and constants:

- M: Mass of the platform
- K: Spring constant
- C: Damping coefficient
- x_p: Displacement of the piston
- x_w: Displacement of the wheel
- F_{spring}: Force exerted by the spring
- $F_{damping}$: Force exerted by the damping system

We now define the forces acting on the system:

$$F_{spring} = -K(x_p - x_w) \text{ (force exerted by the spring)} \quad (1)$$

$$F_{damping} = -C\left(\frac{dx_p}{dt} - \frac{dx_w}{dt}\right) \quad (2)$$

Applying Newton's second law of motion to the platform:

$$M\frac{d^2x_p}{dt^2} = F_{spring} + F_{damping} \quad (3)$$

Assuming that the displacement of the wheel is directly proportional to the displacement of the piston we obtain:

$$x_w = a(x_p) \quad (4)$$

Further, Substituting the forces and displacement relationship into the equation:

$$M\left(\frac{d^2x_p}{dt^2}\right) = -K\left(x_p - a(x_p)\right) - C\left(\frac{dx_p}{dt} - a\left(\frac{dx_p}{dt}\right)\right)$$

$$M\left(\frac{d^2x_p}{dt}\right) = -K(1-a)x_p - C(1-a)\frac{dx_p}{dx} \quad (5)$$

This equation represents the mathematical model for the given system. The mass of the platform (M), the spring constant (K), the damping coefficient (C), and the constant 'a' (relating piston and wheel displacement) are key factors determining the behaviour of the system.

By solving this differential equation with appropriate initial conditions or boundary conditions, one can analyse the response of the system to different terrains and input forces. This mathematical model allows you to study the interaction between the spring, damping system, piston, and wheel, providing insights into the system's ability to absorb shocks and vibrations. The following steps can be used to solve the equation (5):

Let's assume a solution of the form

$$x_{p(t)} = Ae^{rt} \quad (6)$$

where A is a constant and r represents the characteristic root.

Differentiating eqn. (6) we obtain

$$\frac{dx_{p(t)}}{dt} = Are^{rt} \quad \text{and}$$

$$\frac{d^2x_{p(t)}}{dt^2} = \mathrm{A}r^2e^{rt} \quad (7)$$

Substituting these derivatives into the eqn.(5), we get:

$$M(Ar^2e^{rt}) = -K(1-a)(Ae^{rt}) - C(1-a)(Are^{rt}) \quad (8)$$

This equation can be simplified further as follows:

$$Mr^2 + C(1-a)r + K(1-a) = 0 \quad (9)$$

Solving this quadratic equation for r to find the characteristic roots we get:

??

Once we have the values of r, the general solution of $x_{p(t)}$ can be written as a linear combination of exponential functions:

$$x_{p(t)} = A_1e^{r_1t} + A_2e^{r_2t} \quad (10)$$

where A_1 and A_2 are constants determined by the initial conditions.

Solving this equation will give you the displacement of the piston (x_p) as a function of time (t), considering the system parameters M, K, C, and the constant 'a'.

Please note that the specific values of M, K, C, and a, as well as the initial conditions or boundary conditions, need to be provided to obtain numerical solutions.

This paper presents a novel approach to dynamically adjust the position of a vehicle platform utilizing IoT sensors and solenoid valve-controlled gas piston chambers. The system aims to maintain the platform's horizontal orientation while navigating uneven terrains, such as speed breakers. By placing a plate fixed on the axle of each wheel, the IoT sensors accurately measure the platform's height relative to the ground. This height information is then transmitted to the solenoid valves, which regulate the pressure within the gas piston chambers. As the vehicle encounters irregularities in the road, the pistons either raise or lower the platform, allowing the wheels to move independently, ensuring a smooth and level ride for the passengers. The proposed system demonstrates promising results in maintaining platform stability and ride comfort during real-world road conditions. In the next section a mathematical model for controlling the air flow across the piston system is developed. These equations can be used to open and close the valve to raise or lower the piston to maintain the desired orientation of the vehicle.

3. MATHEMATICAL MODELLING FOR AIR-FLOW

To create a mathematical model that correlates the inflow and outflow of air from the enclosed chamber with the motion of the vehicle, we need to consider the dynamics of the system.

Let's define the following variables:

- P: Pressure inside the chamber
- P_{in}: Inflow pressure from the air compressor
- P_{out}: Outflow pressure through the solenoid valves
- V: Volume of the enclosed chamber
- Q_{in}: Inflow rate of air from the air compressor
- Q_{out}: Outflow rate of air through the solenoid valves
- A_{in}: Effective area of the solenoid valves for inflow
- A_{out}: Effective area of the solenoid valves for outflow
- k_b:is a constant dependent on the gas being used in the enclosed chamber and the specific conditions of the system. It relates the pressure (P) and volume (V) of the gas at constant temperature according to Boyle's Law.
- k_g:is a constant dependent on the gas being used in the enclosed

chamber and the specific conditions of the system. It relates the pressure (P) and temperature (T) of the gas at constant volume according to Gay-Lussac's Law.

- R: Gas constant
- T: Temperature inside the chamber

The rate of change of pressure in the chamber is given by:

$$\frac{dP}{dt} = \frac{1}{V}(Q_{in}P_{in} - Q_{out}P_{out}) \tag{11}$$

To determine the inflow rate of air from the compressor, we need to consider the motion of the vehicle as defined by the previous mathematical model:

$$Q_{in} = k(1-a)\frac{dx_p}{dt} \tag{12}$$

Here, k is a constant that relates the vehicle motion to the inflow rate, and $\frac{dx_p}{dt}$ is the velocity of the piston.

The outflow rate of air through the solenoid valves depends on the pressure difference across the valves and their effective areas:

$$Q_{out} = \left(\frac{A_{out}}{\sqrt{RT_{out}}}\right)\sqrt{P} \tag{13}$$

Here, R is the gas constant and T is the temperature inside the chamber.

The pressure inside the chamber during normal trajectory, such as on flat roads, can be determined by setting the inflow and outflow rates equal to each other:

$$Q_{in} = Q_{out} \tag{14}$$

By substituting the expressions for Q_{in} and Q_{out} derived in steps 2 and 3, respectively, and solving 1

To examine how the pressure varies based on the terrain, we need to consider the displacement of the vehicle as described by the mathematical model:

$$X_{p(t)} = A1e^{r1t} + A2e^{r2t} \tag{15}$$

By substituting the displacement $X_{p(t)}$ into the equation for Q_{in}, we can analyze how the inflow rate and, consequently, the pressure inside the chamber vary with time.

It's important to note that specific values for system parameters, such as the effective areas of the solenoid valves, gas constant, temperature, and constants relating the vehicle motion to inflow rate, are required to obtain numerical solutions and accurately calculate the pressure variations in different terrains.

To extend the mathematical model to incorporate Boyle's Law and Gay-Lussac's Law, we can modify the equation for the outflow rate of air through the solenoid valves (eqn.(16))

Here, T_{out} represents the temperature of the outflowing air.

To apply Boyle's Law, we consider the relationship between pressure and volume at constant temperature. Assuming the temperature inside the chamber remains constant, we have:

$$PV = constant \tag{16}$$

We can rewrite this equation as:

$$P = k_b/V \tag{17}$$

Where k_b is a constant related to Boyle's Law.

Similarly, Gay-Lussac's Law relates the pressure and temperature of a gas at constant volume. Assuming the volume of the chamber remains constant, we have:

$$P/T = constant \tag{18}$$

We can rewrite this equation as:

$$P = k_gT \tag{19}$$

Where k_g is a constant related to Gay-Lussac's Law.

By incorporating Boyle's Law and Gay-Lussac's Law into the mathematical model, the relevant equations can be summarized as follows:

$$\frac{dP}{dt} = (\frac{1}{V})(Q_{in}P_{in} - Q_{out}P_{out}) \tag{20}$$

$$Q_{in} = k(1-a)\frac{dx_p}{dt} \tag{21}$$

$$Q_{out} = \left(\frac{A_{out}}{\sqrt{RT_{out}}}\right)\sqrt{P} \tag{22}$$

$$PV = k_b \tag{23}$$

$$P = k_gT \tag{24}$$

To solve the system of equations, additional information such as the specific values of the constants k_b and k_g, along with initial conditions and boundary conditions, are necessary. These values can be determined experimentally or through detailed analysis of the system components.

4. VARIOUS APPLICATIONS OF THE PISTON SYSTEM

In this section, we discuss the integration of an IoT-controlled piston system in conjunction with a shock absorber to address different frequency ranges of road irregularities, thereby optimizing vehicle ride comfort. The shock absorber effectively mitigates high-frequency vibrations, while the piston system is designed to handle low-frequency disturbances, particularly encountered in speed breakers and uneven terrains. The presence of speed breakers is detected either through real-time IoT sensors or pre-determined using GPS signals, enabling the onboard computer to anticipate these obstacles. As the vehicle approaches a speed breaker, the system employs a two-step approach: first, the vehicle speed is reduced to minimize discomfort caused by high-frequency vibrations, and subsequently, the piston system is activated as needed to maintain platform levelness. This proactive adaptation ensures a smooth ride experience for passengers, effectively minimizing the impact of road irregularities on the vehicle's stability and comfort. The following three methods illustrate the coordinated functioning of the piston system and shock absorber to optimize ride quality under varying road conditions.

4.1 Model 1: Modified Macpherson Suspension System

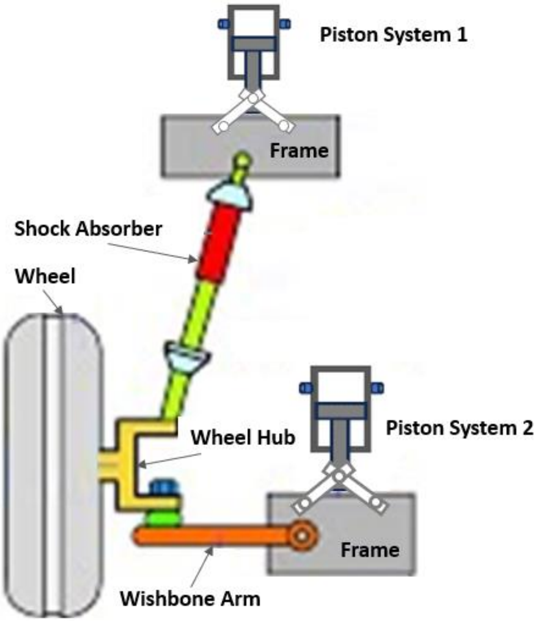


Figure 2: Modified Macpherson Suspension System using two Pistons

The Macpherson suspension system, named after its inventor Earle S. Macpherson, is a widely used and highly regarded automotive suspension design. It is a type of independent suspension commonly found in front-wheel-drive vehicles. The system consists of a single telescopic shock absorber connected to the lower control arm and the vehicle's body. The upper part of the shock absorber is attached to a reinforced strut mount, which acts as both a pivot point and a damping element. This simple and compact design provides excellent handling, stability, and ride comfort, making it a popular choice for modern vehicles. This system can be further modified to increase comfort by adding two piston systems to the frame as shown in figure 2. These two pistons will be activated in accordance with the signals received from a height detection transducer in order to compensate for low frequency uneven surfaces on a road such as a speed breaker. A further improvement is possible by fixing the piston directly on the wishbone arm and the shock absorber without unnecessarily mounting them on the frame. The frame would be mounted on the top of the piston systems instead.

4.2 Model-2: Independent Rear Wheel Suspension

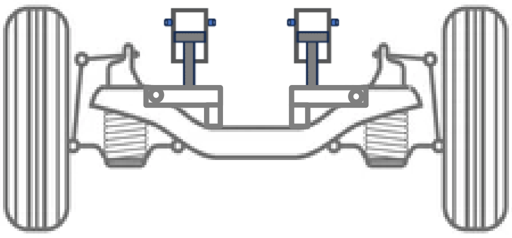
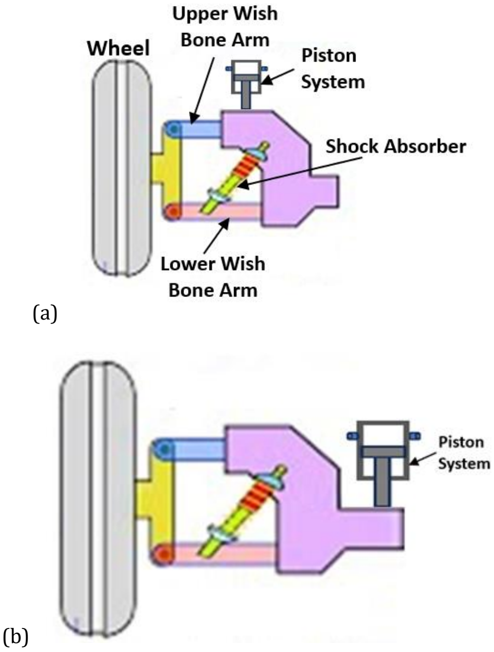


Figure 3: Example of Use of Piston suspensions on Independent Rear Suspension

Independent rear suspension (IRS) is a type of suspension system that allows each rear wheel to move independently of the other as shown in figure 3. This is in contrast to traditional solid axle setups, where both wheels are connected together and move as a single unit. The main advantage of IRS is that it provides better handling, comfort, and stability. This is because each wheel can independently adjust to road irregularities, which helps to maintain tire contact with the road surface and reduce body roll. As a result, IRS systems can significantly improve the overall driving performance and passenger comfort of a vehicle. This system can be further improved by adding two piston systems as shown in figure 3. These piston systems will be activated only when the large amplitude hurdles like the speed breaker is detected.

4.3 Model 3: Double wishbone suspension system



(a)

(b)

Figure 4: Double wish bone suspension system with the Piston system (a) on the top (b) on the bottom.

Double wishbone suspension (DWS) is a type of independent suspension that is widely used in automobiles. It is known for its precise handling and superior ride characteristics. The DWS system consists of two wishbone-shaped control arms for each wheel. The upper and lower control arms are connected to the vehicle chassis and wheel hub, respectively. This allows the wheels to move vertically and independently from each other. The DWS system has a number of advantages over other types of suspension systems. These advantages include:

Precise handling: The DWS system allows for precise control of the wheels, which results in better handling and stability.

Superior ride comfort: The DWS system can provide a smoother ride than other types of suspension systems. This is because the wheels are able to move independently, which helps to absorb bumps and vibrations.

Reduced camber changes: The DWS system helps to reduce camber changes during suspension travel. This means that the tires maintain better contact with the road, which improves handling and traction.

The DWS system is used in a variety of vehicle platforms, including sports cars, luxury cars, and performance sedans. It is also used in some commercial vehicles. However, this system is still unable to handle low frequency, large amplitude movement caused by speed breakers. Figure 4 shows two alternate ways in which the piston system could be employed to accomplish the task of maintaining the height of the vehicle while the wheel traces the speed breaker, thus further improving the comfort to the riders on the vehicles.

4.4 Model-4 Piston System under the vehicle seat

Figure 5: The piston systems are mounted underneath the seat of the vehicle

In this case rather than attaching anything new to the wheel and the axle, four independent piston systems to the car seats directly as shown in the figure 5. These pistons will be programmed to react to stimulus based on the IoT sensors and the gas flow to the inlet and outlet valves can be controlled to raise or lower the seat in response to the stimulus. The advantages are that the system can independently help a single or multiple passengers as desired.

4.5 Model 5: Detached Piston system and Strut assembly

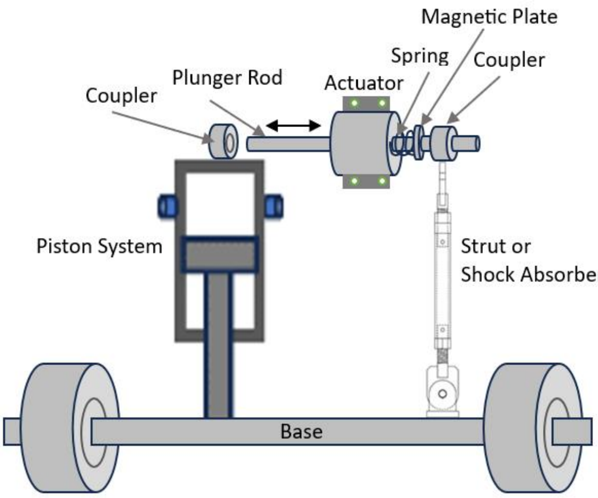


Figure 6: Engager system that allows the engagement of either the piston system or the strut using a plunger through an actuator connected to the chassis of the vehicle

In contrast to the four earlier models described herein, the aforementioned model distinguishes itself through a departure from prior design conventions. Notably, this deviation pertains to the discreet nature of the enclosed piston chamber and the spring-based strut system. Unlike previous iterations, these components operate independently of each other, possessing separate attachments to a common axle system. Notably, their operational dynamics remain unlinked, as they function autonomously. This configuration entails the establishment of an attachment system that is purposefully engineered to facilitate the engagement of either the spring-based strut or the piston chamber contingent upon prevailing terrain conditions, as shown in figure 6. In this figure 6, an actuator is used that moves the plunger from Piston system to the Strut depending on the requirement. At any given time only one of the two systems is engaged, this enables the vehicle to switch from a high frequency shock absorption mode to the low frequency shock absorption mode.

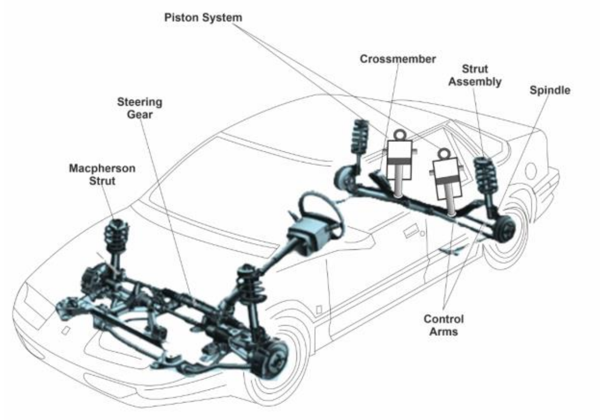


Figure 7: Two Piston systems attached to the cross member of the rear wheels in the car

Figure 7 shows two piston systems attached to the cross member of the rear wheels in the car that provides comfort to the passengers in the rear seats. However, if the comfort has to be experienced by the passenger and the driver in the front seat, similar piston systems would have to be appropriately mounted on the front wheel assembly as well.

5. CONCLUSION

In conclusion, this paper presents a novel approach to dynamically adjust the position of a vehicle platform utilizing IoT sensors and solenoid valve-controlled gas piston chambers. The proposed system aims to maintain the platform's horizontal orientation while navigating uneven terrains, such as speed breakers, and has demonstrated promising results in maintaining platform stability and ride comfort during real-world road conditions. The mathematical model developed for controlling the air flow across the piston system provides a framework for opening and closing the valve to raise or lower the piston to maintain the desired orientation of the vehicle. The proposed system has the potential to enhance ride comfort and safety in vehicles, and future research could focus on the development of adaptive suspension systems that can automatically adjust to different driving conditions. Overall, the integration of electronics with mechanical components has the potential to revolutionize the traditional suspension system and improve ride comfort and safety for passengers.

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