Development of A New Automotive Active Suspension System

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Abstract. The main objective was to develop a smart new vehicle suspension system that minimizes the road irregularities impact on the driver, also to increase performance and stability of the vehicle at high speeds. The central idea is based on modifying the normal passive suspension system into a computer controller hydraulic actuated active suspension system simply by adding a new component such as a hydraulic cylinder on a normal passive system. The new suspension system is economical to be wildly used in consumer’s cars with low prices. The new added components was analytically tested and modeled according to different parameters. A new test rig was implemented to simulate a real quarter suspension system. The new suspension model was controlled by feedback controller according to the road conditions; the controller output controls the cylinder actuator to compensate the road oscillations and increases the vehicle stability for the passenger. Finally, to maximize the aerodynamics coefficients of the vehicle during high speeds by controlling the vehicle clearance level from the ground to achieve full stability, steering and fuel economy.

1. Introduction
Suspension system is the most important part which heavily affects the vehicle performance and ride quality. Traditional suspension systems use sets of springs and sets of dampers to decrease the vehicle vibration called passive suspension system as shown in figure 1. [1-2]

For the active suspension systems shown in figure 2 can automatically vary its height to maintain the vehicle steady have been an active area of research over the last two decades to achieve a better compromise during varying driving conditions. The active suspension system involves multiple complex technical problems, such as mechanology material science and electronics. [3]

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{GENERAL_SUSPENSION.png}
\caption{General Suspension System}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{ACTIVE_SUSPENSION.png}
\caption{Active Suspension Systems}
\end{figure}
An active suspension more effectively reacts to the change in speed and while the car is cornering too, so that to make the ride to be more comfortable and steady, however it is more expensive than the passive suspension system [4].

This paper aims to develop a new suspension system to achieve passive and active suspension system advantages such as performance efficiency and cost.

2. The Design of the new Suspension System

Passive suspensions as illustrated in figure 3 achieves good ride comfort or good road holding since these two criteria conflict each other and require different spring and damper characteristics[5].

A significant improvement can be achieved by using of an active suspension system presented in figure 4 which supplied a higher power from an external source (Hydraulic Cylinder) to generate suspension forces to achieve the desired performance. The force is a function of several variables which can be measured or remotely sensed by various sensors, so the flexibility can be greatly increased.

![Figure 3. Passive suspension system](image1)

![Figure 4. The New Designed Active Suspension System](image2)

To understand the new suspension system in a fundamental and quantitative way, a mathematical model shown in figure 5 must be obtained to represent the real world problem in mathematical form with some simplified assumptions. The mathematical model is also important to make sure that the new suspension system is controllable and observable.
Figure 5. The New Designed Active Suspension System Mathematical Model

Automotive companies are challenging to make more developed cars, while comfort of passengers is an important demand and everyone expects from industries to improve it day by day. Therefore, in order to provide a smooth ride and satisfy passengers comfort while maintaining the high performance of a vehicle designing a modern suspension system is essential. A good and efficient suspension system must rapidly absorb road shocks and then return to its normal position, slowly, during low speeds however at high speeds the suspension system should increase the stability and performance by lowering the vehicle’s clearance level from the ground [6-7].

3. Suspension System Control Mechanism

In order to fulfill the objective of designing a new active suspension system i.e. to increase the ride comfort, road handling, and performance, two control systems are developed.

The first is the disturbance road absorption control system that absorbs the oscillation on the vehicle’s passenger from the road irregularities to increase the ride comfort. The other is the height adjustment control system that adjusts the clearance level from the ground of the vehicle according to its speed to increase the stability and the performance.

The Disturbance Absorption Cylinder control system consists of PID Controller, Ultrasonic Sensor, and an interface circuit.

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The PID Controller input signals are the Ultrasonic Sensor and the Wheel Speed Sensor output signal. The error signal shown in figure 6 of the PID controller is the difference between the output signal of the Ultrasonic Sensor to the reference set point. Then according to the calculated error the PID Controller outputs a signal shown in figure 7 to the disturbance absorption cylinder’s solenoid valve accordingly through the interface circuit, an Amplifier.

Figure 6. PID Controller error elimination: The blue line is the optimum error signal and the yellow line is tuned the error of the PID Controller

Figure 7. PID Controller Step Plot: Reference Tracking

The red line is the reference tracking constant meters and the blue line is the tuned response of the PID controller.

In the new active suspension system the ultrasonic sensor function is to measure the distance from the damper to the road disturbance absorption cylinder. The Ultrasonic Sensor readings output signal is shown in figure 9. The position of the ultrasonic sensor on the new suspension system is shown below in figure 8.
In figure 9 the blue line is the optimum position of $m_c$, vehicle’s displacement position which is 1.05 meters and the yellow line is the actual displacement position of the $m_c$, the Ultrasonic Sensor readings output.

For the Height Adjustment control system, to prove the fact that lowering the vehicle’s height as the speed increases maximizes the vehicle’s efficiency by decreasing the lift and drag coefficients; three Solid Works flow simulation tests are performed on a vehicle, shown in figure 10, designed according to the specifications of the minimum and maximum clearance level from the ground.

After applying the flow Solid Work simulation test on the vehicle at different clearance levels from the ground, comparisons of the lift and drag coefficients are shown in table 1 and in figure 11 to prove that as the clearance level from the ground decreases the lift and drag coefficients decrease thus increasing the vehicle’s performance, stability, and fuel economy.
Table 1: Comparison of the Lift and Drag Coefficients for Normal, Mid, and Low Modes

| Vehicle’s clearance level from the ground | Lift   | Drag   | Comparison |
|-----------------------------------------|--------|--------|------------|
| Normal mode (clearance 6.5 inches)      | 169.29 | 266.11 | Low        |
| Mid mode (clearance 5.5 inches)         | 132.94 | 262.69 | Lower      |
| Low mode (clearance 4.8 inches)         | 26.91  | 176.06 | Lowest     |

The height Adjustment Control System consists of an Arduino Controller, Wheel Speed Sensor, and an interface circuit.

The Arduino Controller input signal is the wheel speed sensor output signal. This signal is digital pulses with different frequencies according to the speed of the vehicle function. Then according to this output signal the Arduino Controller outputs a signal to the disturbance absorption cylinder’s solenoid valve through the interface circuit, an Amplifier, and a Low pass filter.

In the height adjustment controller, the road disturbance absorption cylinder interface circuit connects the Arduino to the Directional proportional control valve. The interface circuit consists of an amplifier and a low pass filter.

4. Conclusion
A unique automotive active suspension system design, control, and implementation was the main thesis objective, to go through this task, the following research was covered through the thesis chapters.

Firstly different suspensions were analyzed from pervious researches. According to the variable gain for the car body velocity and acceleration, the combined suspension system with a hydraulic cylinder shows the best performance.

Then the PID controller was applied to let the suspension system with hydraulic actuator track the ideal force generated from the combined suspension system with hydraulic actuator. The performance of the four states including sprung mass position, velocity, unsprung mass position and velocity are worked on.

After that the electrical model control is applied to the suspension system with the hydraulic actuator. The control input is designed based on the model of PID control principle to minimize the tracking error between the actual force generated by hydraulic actuator and ideal force obtained by the combined suspension system with hydraulic cylinder.

Finally the practical implementation of the whole new suspension system was tested and compared to the theoretical results of the passive suspension system and new suspension.

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