Ultrasonic Sonar controlled Active suspension system using Arduino

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Abstract: This paper deals with a system that uses Ultrasonic sensors in combination with Arduino to result in a controlled vehicle Suspension system. This system is aimed at being a cost-effective alternative to the active suspension systems available in the vehicles today. The performance of this system is simulated using MATLAB by deriving its mathematical model of a quarter car model and drawing comparison with passive suspension systems. The selection of the system components, like the servo motor, where the output is obtained is in view with the system being capable to adapt to a large-scale model. The simulation is carried out for various road/terrain conditions and the reaction is observed. A Simulink model is constructed to test the range of obtainable control of the system, like the reaction speed of the system and ride height.

Keywords–**Active suspension system, HC-SR04, Servo motors, Arduino, Simulink, Simscape.**

I. INTRODUCTION

1.1 Suspension System

The primary functions of the suspension system are to provide ride quality and tractive effect, in parallel the system also protects the vehicle or the cargo from wear. The most significant function is to provide the comfortable drive to the passengers while travelling in all the types of terrain and to ensure terrain grip at all circumstances.
As the vehicle travels over an irregularity in the road, there is energy produced in the form of vibrations and are absorbed by the spring and in turn dissipated by the dampers. The vibrations are transferred all the way up to the chassis and realized by the passenger only when the components undergo ultimate wear.

1.2 Arduino Uno

Arduino Uno is a programmable microcontroller with a set of both digital and analog input/output (I/O). It has 14 digital pins and 6 analog pins for input/output and can be programmed with Arduino Integrated Development Environment (Arduino IDE). The Arduino board being user friendly without major complications finds its application in the field of robotics, AI based projects and is also used to build and create new devices. There are various types Arduino boards available in the market and among them Arduino Uno is a standard variant and is generally preferred. The microcontroller takes the input from the electronic devices and allows the user to control the outputs from the same.

1.3 Servo Motor

The servo motor is a type of an actuator that allows rotary or linear actuation and provides ultimate control over its angular or linear positions, acceleration and its velocity. It takes the feedback about its position from a sensor that is couples to the motor. The operation of the servo motor is generally controlled by a controller module designed specifically for the application. A servo motor acts as a closed loop mechanism as it takes feedback about its position to control its own motion. Apart from the main control circuit servo motors incorporate other subcomponents such as a dc motor, a position sensing device, a reduction gear unit.

II. METHODOLOGY

The details of the methodology carried out in building the system has been highlighted under the following headings.

- Mathematical modelling
- Simulink modelling
- Simscape
- Programming the Arduino
    - Simulink model to test response.

2.1 Mathematical Modeling

The same system is subjected to different input signal sources like step signal and sine wave signal and the output is recorded in rectifying the controlled system performance outperforming the passive system. The Active suspension system proposals can use different algorithms and ideas for arriving at the goal of handling vehicle jerks, thereby ensuring ride comfort and safety. The main difference between a Passive and Active suspension is that it traces or makes the wheel move according to the disturbance passed on to them from the imperfections on the road. In case of Active suspension, it is able to sense these imperfections and make the ride react to it with the necessary adjustments to cancel the forces being transmitted further. The goal with this project is to simulate one such system proposal is to obtain realistic dynamic performance. This is done by building a suspension rig on a scale closer to the actual commercial car.

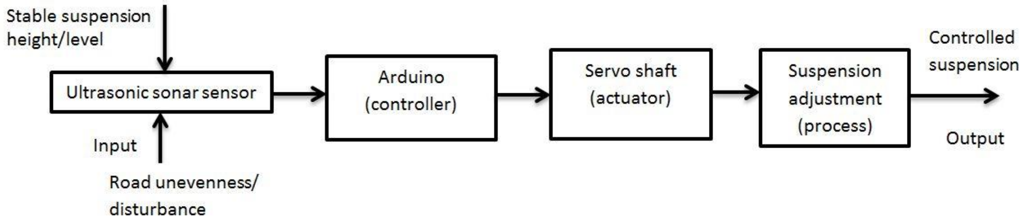


Figure 2.1 - Block diagram for the open loop system of the suspension system

Considering a quarter car model, the forces active in a spring-mass-dashpot system is as shown in Fig. 2.2. Further simplification is obtained with the free body diagram.

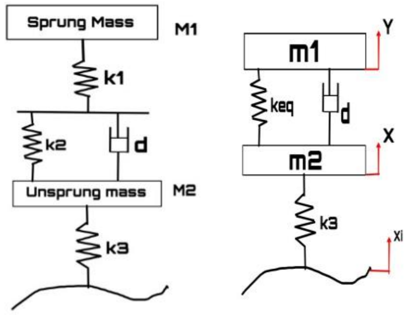


Figure 2.2- Free body diagram of the suspension system.

$$y(s)/xi(s) = (keq\,k3 + k3ds)/(m1m2s4 - m1keqs2 - m1ds3 - m2keqs2 - m2ds3 + keqk3 + k3ds) \quad (1)$$

where,
k1 and k2= spring stiffness
keq= equivalent spring stiffness
m1 and m2= sprung and unsprung mass
ds=damping co-efficient.

Hence the above equation is used in the formulation of the transfer function in Simulink.

2.2 Simulink Modeling

The Simulink model shown in Fig. 2.3 combines both passive and the controlled active suspension systems and the output obtained through the scope gives the comparison between the performances of the system. The additional component used for the active suspension system is the Proportional Integrative Derivative (PID) controller to simulate the controller of the system which is the Arduino.

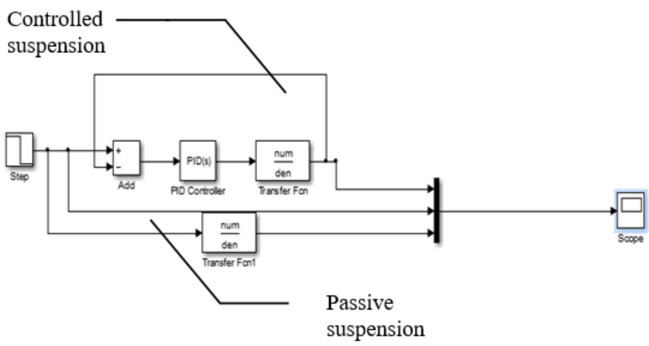


Figure 2.3- Simulink model of an active suspension system with step input signal

The same system is subjected to different input signal sources like step signal and sine wave signal and the output is recorded in rectifying the controlled system performance outperforming the passive system.

Table 1 – Input values of the physical system

Symbol	Vehicle Model Parameters	Values	Unit
Mass1	Sprung mass	300	Kg
Mass	Unsprung mass	40	Kg
Spring1	Suspension Stiffness	4200	N/m
Spring3	Tire Stiffness	8000	N/m
Damping	Damper	1000	Ns/m

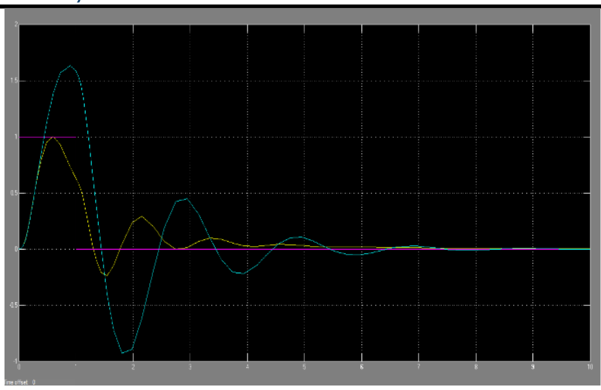


Figure 2.4 - Combined output for passive and active suspension system

The displacement output response graph of the Simulink system above shows that the controlled suspension (yellow) has better efficiency in suppressing the travel of the disturbance (purple), while that of the passive suspension (green) takes more time in dampening the disturbance.

2.3 Simscape

Simscape is a platform which is used to construct and simulate virtual systems before constructing prototypes. Simscape is used to construct an active suspension system actuated by DC servo motor. The suspension system can be further divided into two parts:-

- Construction of spring mass dashpot system
- Construction of DC servo motor

Spring mass dashpot system

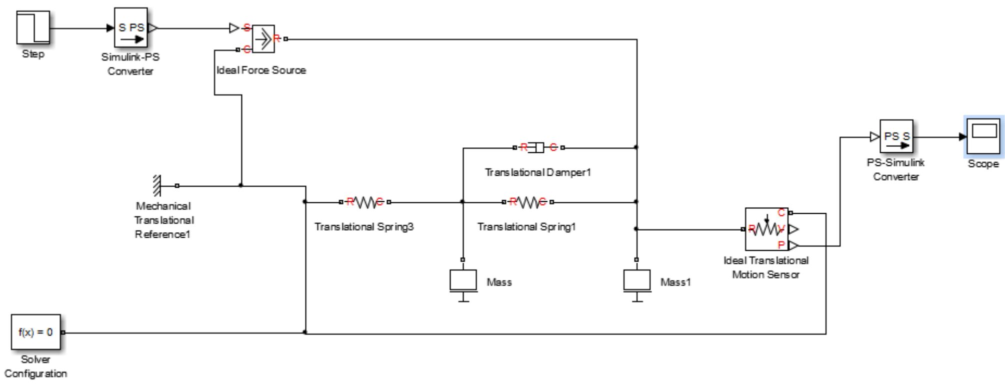


Figure 2.5 –Physical representation of spring mass dashpot system

Since this spring mass damper system represents the Passive suspension system, the displacement of the suspension system with step input signal (resembles a bump on the road) is shown in Fig. 2.6.

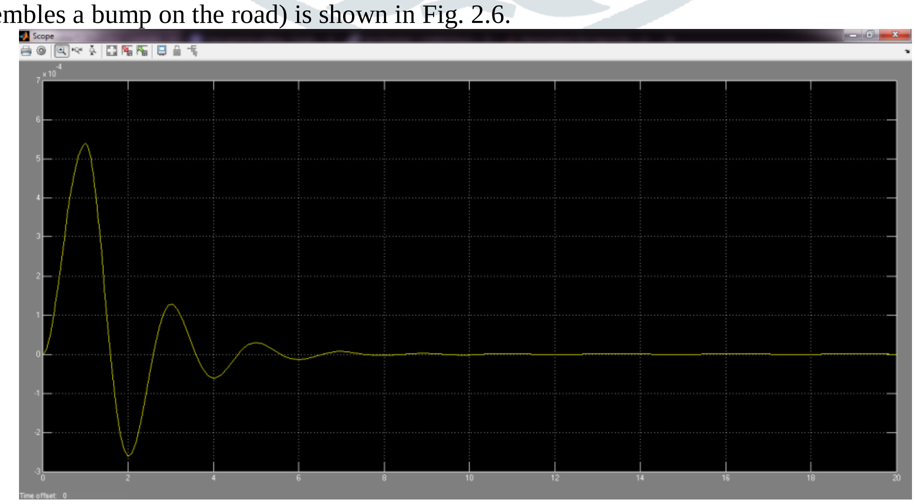


Figure 2.6 – Displacement graph of passive suspension system

The positive and negative peaks of the displacements are +5.4 and -2.8 (approx.) respectively and the settling time is 7 seconds.

Construction of DC Motor

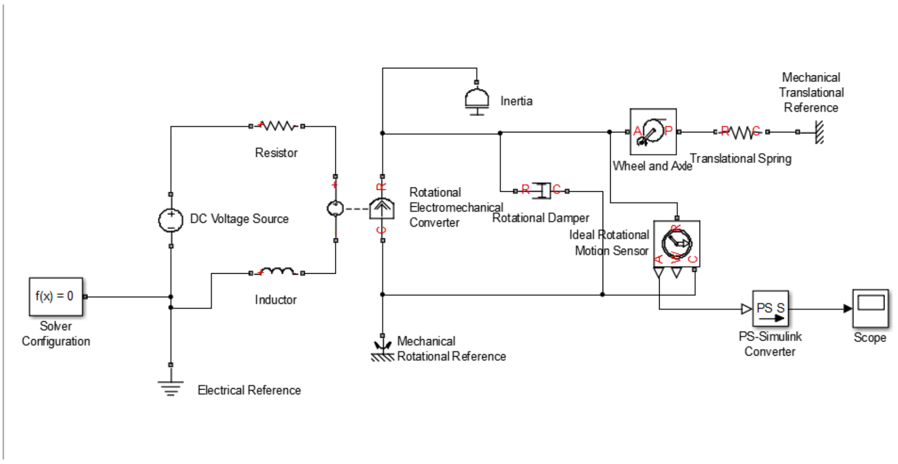


Figure 2.7–DC Servo motor

Combining the spring mass dashpot system (passive suspension system) and DC servo motor

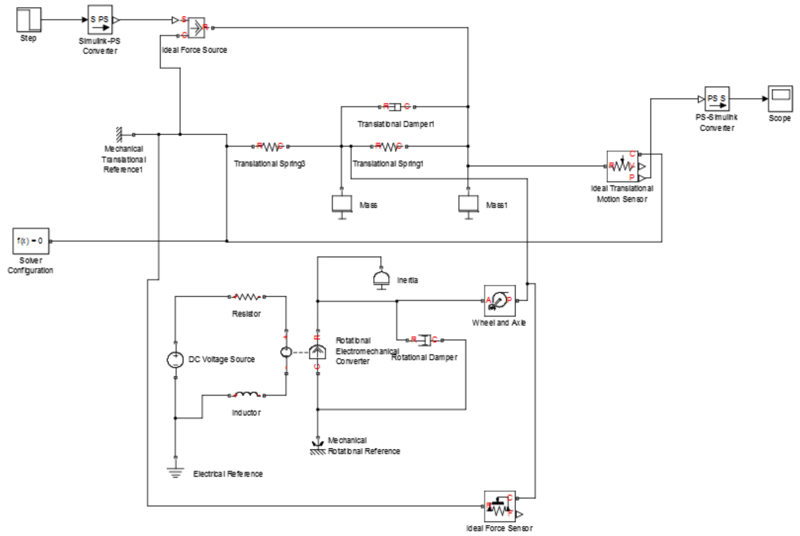


Figure 2.8–Physical Model of an active suspension system actuated by a DC servo motor

On running the system, we get a displacement graph as shown in Fig, 2.9.

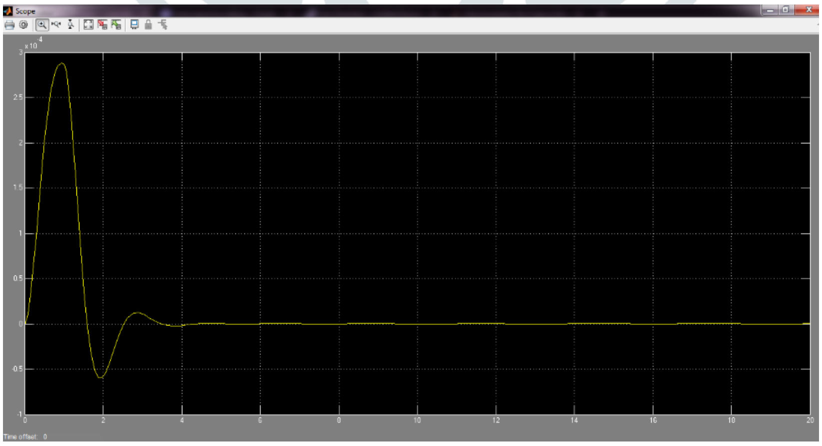


Figure 2.9–Displacement graph of Active suspension system

The positive and negative peaks of the displacement are +2.8 and -0.51 (approx.) respectively and the settling time is 4 seconds. On comparing, the suspension system actuated by DC servo motor portrays a better performance than the conventional spring mass dashpot system.

2.4 Programming the Arduino

The code for the Arduino needs to be such that it incorporates the capability to read data from the Ultrasonic sensor and in turn send the same to the servo motor as input. The code for this purpose uses the NewPing library to enable interface between the Arduino and the sonar sensor. With the use of a map function, the output data of the ultrasonic sensor is being mapped to the servo motor as angles in the specified range of motion.

```
void loop() {
  int cm= sonar.ping_cm();
  Serial.println(cm);

  int angle = map(cm,0,35,90,180);
  servo.write(angle);

  delay(60);
 }
```

Figure 2.10 –Arduino code

The output of the program hence makes the servo motor shaft rotate in sync with the change in the distance being sensed by the sonar sensor.
Int angle = map (cm, 0, 35, 90, 180);
Here 0 and 35cms become the range within which the sonar detects disturbance or change, and 90- 180 degrees is the servo shaft's range of rotation. This movement of the servo shaft can therefore be used aiding the suspension adjust itself over the irregularity picked up by the sensor. Upon uploading the program to the board, the serial monitor of the Arduino IDE outputs the distance measured by the sonar in real time.
By changing the value of the delay in program, the response time of the suspension can be changed. Changing the delay to a larger value sets the reaction of the servo to react slowly and hence obtaining a softer suspension and ride quality. With a smaller delay value in the code will result in a fast reacting suspension setup, which is a harder suspension aimed at extracting the maximum performance of the vehicle. This is experimented by constructing a separate Simulink model recording the reaction of the sonar and the servo angle movement.

2.5 Simulink model to test output.
A Simulink model that incorporates the sonar and servo, whose output with which the reaction is tested, is as shown in Fig. 2.11.

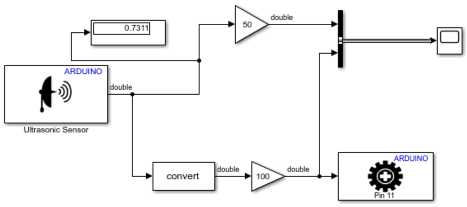


Figure 2.11–Simulink model

The gain blocks seen in the model are to amplify the digital signal inorder to be visble in the output response graph. A conversion block between the ultrasonic sensor and the servo to matches the servo signal type to real world values. On running the Simulink model, the output response graph shows the distance picked up by the ultrasonic sensor and the servo motor shaft roatating accordingly within the specified limits in the mapping fucntion. The display from the scope is as seen in the Fig. 2.12. The red line in the scope denotes the signals picked up by the Ultrasonic sensor, which is the distance to the distrubance it senses. For example, the distance sensed by the sensor remains constant when the vehcile is in it's idle/ resting condition which is the level or the height at which the vehicle floor sits from the ground. Keeping the sensor facing the ground, it is constantly sensing the change or disturbance to the road's surface. This results in the sonar picking up the height of the bump, or the depth of a pothole by sensing how far or close they are from the sensor. Therfore with the mapping function, prompts the servo shaft to roate accordingly and can dampen the distubance being passed on further up the vehicle.

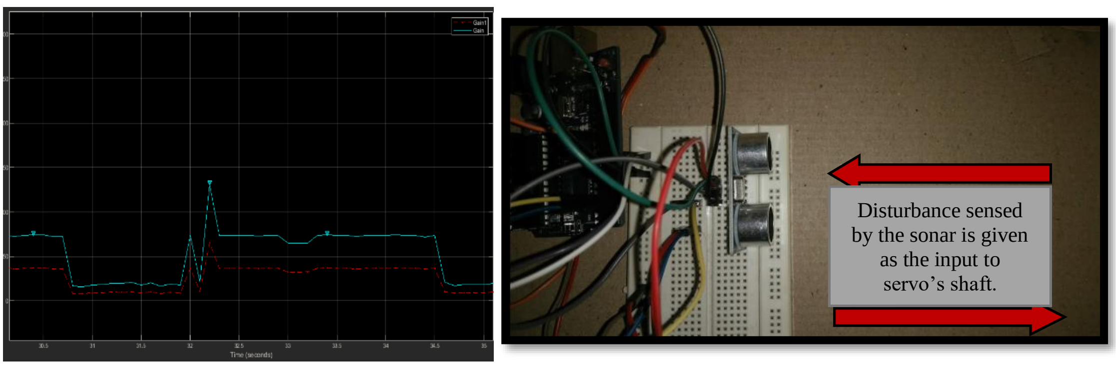


Fig. 2.12 –Output response graph

2.6 Linkages

In the view to implement the active suspension rig that has been built, the next step would be the implementation of the same on a prototype and test its performance. In order to proceed about the step, the focus would be to study the working of a conventional suspension system and its components, and arrive at adapting the proposed model to it. Even though there are Active suspension systems available in many vehicles, they are generally included in the high-end versions of a company's model. These suspension systems are costlier and as much complex in nature. Keeping these factors in mind, the best way to adapt the Active suspension rig would be to keep in check the cost incurred in the adaptation, involving minor changes to a conventional suspension but achieve the goal of making it smarter and efficient.

Studying their means of achieving control over the vehicles suspension allowed us to understand its working and has resulted in the incorporation of a similar theoretical design. Fig. 2.12 is in reference to small scale model of a vehicle that has been considered for this project. Theoretical sketch for such a system is as shown in Fig. 2.13.

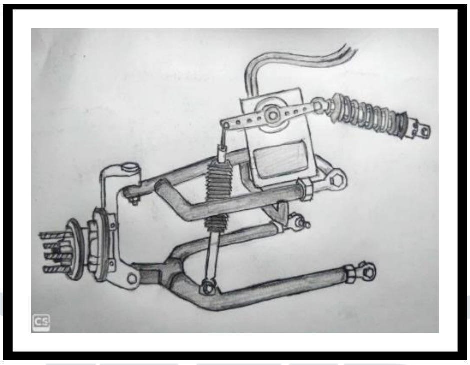


Figure 2.13–Theoretical sketch for designed system

The servo situated on the control arm section allows for it move according to its outputted movement calculated by the Arduino getting the input from the sonar sensor. However, this style of arrangement causes the vehicle weight to rest on the servo flap, which shouldn't be a problem for a small-scale model. This prototype vehicle's suspension system performance can hence be tested in the real world up to a certain extent.

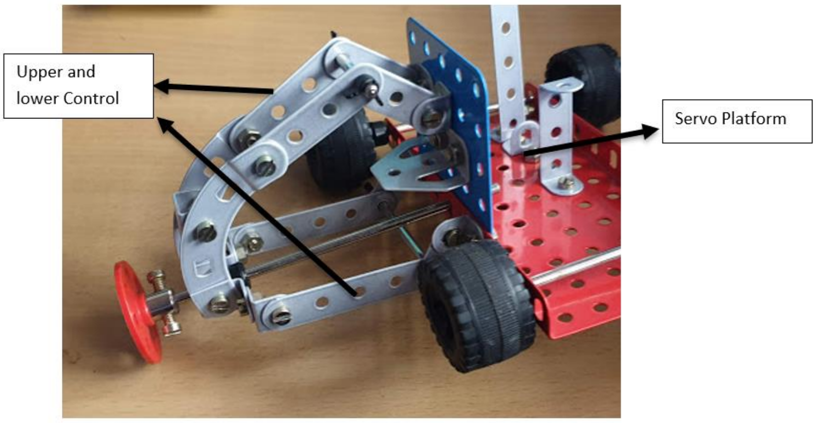
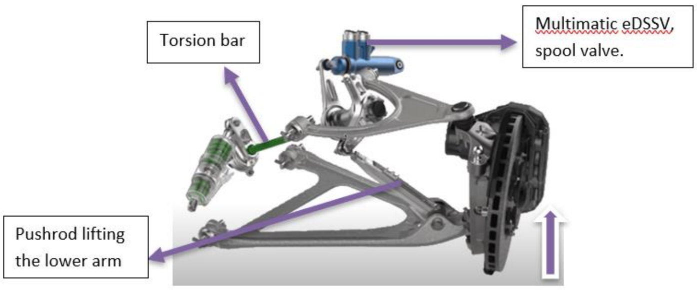


Figure 2.14–Prototype model linkage test

Moving on to the implementation in a bigger actual scale, the system remains the same but the actuator or the control has to be varied. A pneumatic cylinder can be used as a viable replacement for the servo motor in a larger scaled model application. However, in order to provide solid validity of this proposal theoretically, there need to be considerations of the vehicles center of gravity based on the engine positions. A front mounted engine vehicle will have majority of its weight in the front, and in the rear for a rear mounted vehicle and the best of both worlds in the case of a mid-engine vehicle.



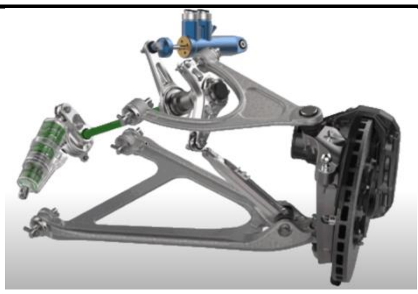


Figure 2.15–Extraction and Retraction of cylinder

III. CONCLUSION

Suspension system is the most important part of an automobile that determines the ride quality, safety, road grip and provides the relative motion between the sprung and un-sprung mass of the vehicle. It consists of components such as coil spring, dampers, mechanical struts, etc. Over the years the automotive industries have adapted the technological improvements to improvise and obtain a smarter and efficient suspension system and thus, the suspension system is broadly classified as Passive, Semi-Active, Active suspension system. However, these systems are extremely expensive and are harder to maintain, hence an alternative design for an active suspension was designed using ultrasonic sensor, an Arduino unit, and servo motor. The idea behind this particular design was to create a cheaper model of suspension system that can effectively perform all the functions as that of the conventional active suspension system.

The designed was theoretically tested by creating mathematical models and feeding the same to two different domains in the MATLAB tool. The design was tested under Simulink and Simscape tools and both the results proved that the new design performed the functions of active system as it had a convenient output graph when compared to the passive system. To demonstrate the mechanical functioning of this system, a small scaled linkage was constructed and attached to the activating unit.

Although a model of 1:1 ratio couldn't be fabricated for the design, it was concluded theoretically that the new design performed on par with the conventional active suspension system and could be implemented as a cheaper alternative.

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