Application of Accelerometer in the Design and Adaptation of Active Suspension in Automobile

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Abstract. Upon the pedigree of technological advancement till our contemporary world, there has been an immense increment and improvement in the automotive industry like the development of vehicle suspension systems to suit the need of their customers whether it is soft (for comfort) or stiff (for good road holding capability for sports vehicle) or even a vehicle suspension system that can switch between these two modes. This research work focused on the effect and application of accelerometer in the design of an active suspension system using a microcontroller. It presents the control method implemented to keep the model vehicle leveled over pitching motions of the vehicle and the design of its component parts as well as the computer program to perform this action. The result showed that over different inclined surfaces the actuator was able to change the wheel travel of both the rear and front wheels to keep the vehicle chassis leveled. These suggest possible adaptation of the design and improvement efforts which has capacity in addressing challenges of vehicles plying different road surfaces.

Keywords: Suspension; Active suspension; Accelerometer; Microcontroller.

1 Introduction

Vehicle suspension systems are being designed constantly to make travelling in motor-vehicles safer and more comfortable, from the inception of transport vehicles, animal-drawn coaches had suspension systems designed into the coaches, and this was because the paths on which these vehicles travel on are always uneven. Prior to the design and installation of suspension systems on wheeled carts and coaches, the axle of the road wheels was fixed to the body of the cart, this meant that for every vertical distance travelled by the wheel over bumps or down depressions on the road surface, this causes the body of the vehicle to rotate in different directions relative to the wheel travel of the vehicle.

The earliest suspension system was the Leaf Spring Axle suspension, with the level of technology available at that period, beam spring made of wrought-iron were arranged together in layers until the required stiffness was obtained, their beams are usually in curved shape and single spring beams were also used [2]. Suspension systems are of two types namely the Dependent and Independent Suspension systems, in the dependent suspension system, the motion of one wheel affects the other wheel as they are both connected to a rigid member, whereas in the Independent Suspension system, each wheel can move on its own accord without transmitting any force to the other road wheel.

1.1 Suspension Classification

1.1.1 Passive Suspension

A conventional suspension system (passive suspension system) is made of three elemental components according to [7] which are the:

- Elastic component (most commonly a coil springs and leaf springs then there is the more recent air springs).
- Damping component to reduce the oscillation (vibration).
Mechanical Linkages that join the body of the vehicle to the road wheels.

The passive suspension is limited in its design as different road conditions cause wheels to move vertically with different forces and speeds and the stiffness of the spring and damping factor of the damper cannot cause the wheel to move with a force that is equal to the force caused by the bump.

1.1.2 Active Suspension
Active suspension in automobiles is any suspension system in which the wheel-travel is controlled electronically independent of the response to the road surface condition. This system comprises of electronic control unit which receives signals about the road condition via sensors, the electronic control unit sends signals to the actuator to alter the wheel-travel on each road wheel. They are classified according to two main features [9]:

1.1.2.1 Energy input:
Passive, Active and Semi-active suspensions are the three types of suspension systems under this class. Suspension system that does not possess any energy input on any of its suspension components is Passive suspension. However, when energy is added to the system it is an Active suspension and if the system is electronically modified but energy is not added, it is a Semi-active or Adaptive suspension. Active suspensions are those that can change the ride height of the vehicle while Semi-active suspensions are those that cannot change the ride height.

1.1.2.2 Bandwidth:
It is specific reaction-time of the electronically controlled elements. For an active suspension, it has every elemental component of the conventional and has a suspension electronic control unit (ECU) and sensors that detects physical variables. These two elements work together to change or alter the reaction of the road wheels to the road surface conditions. The suspension ECU controls the actuator and other components. The ECAS (Electronically Controlled Active Suspension) vehicle has capabilities to change the acceleration of the sprung mass continuously [1].

1.1.3 Active Stabilizer System
Active stabilizer system is an active suspension system that involves using an electronic system to control the deflection of the stabilizer bar. The passive stabilizer bar is used to reduce vehicle roll by transmitting the part of the vertical motion of one wheel on a side of the vehicle to the other (from right to left and vice versa). The portion of the motion transmitted is proportional to the stiffness of the stabilizer bar. When one wheel experiences force acting on it, the force acts on one end of the bar to produce a torque which is transmitted to the other end of the bar thereby causing that wheel to move in the same direction as the other. Although, this system is not favorable in all situations, for instance when driving off-road, this stabilizer bar system causes one or more wheels to lose contact with the ground surface. The stabilizer bar stiffness cannot be changed to fit all road conditions; the Active Stabilizer System was designed to overcome this challenge by changing the stiffness of the stabilizer automatically or on demand by the driver [10].

1.1.4 Predictive Suspension
The predictive suspension system is the future active suspension system, it uses stereo cameras to scan the surface of the road ahead of the vehicle, this image is fed into an onboard computer that processes the image to determine the nature of the surface, the onboard computer controls the suspension actuators to raise or lower the individual wheels thereby keeping the chassis of the vehicle near horizontal level [4-5].

Active suspension systems have the capability to reduce the motion of the body of the vehicle which is the sprung mass of the suspension system thereby increasing comfort, braking, traction and maneuverability. For a passive suspension system to provide comfort, parameters like the damping factor, the wheel travel and the spring stiffness have to be changed, the wheel travel has to be increased, the damping coefficient and the spring stiffness constant has to be reduced. For the active suspension system to vary these
parameters, there are quite a number of control methods, methods such as Non-linear control, Linear Quadratic Gaussian (LQG) control, Proportional Integral Derivative control (PID) and adaptive control, however in the past Fuzzy Logic Control (FLC) which was developed by Zadeh [1].

1.2 Skyhook Theory
The Skyhook theory is an idealized active suspension system that allows a vehicle to maintain its leveled position as if it were suspended by an imaginary hook from the sky, regardless of the road conditions (Skyhook Theory, n.d.). This theory is not practical because the vehicle’s wheel travel for an active suspension system is controlled by actuators. For a vehicle to maintain its leveled position it must have zero vertical acceleration, the acceleration is measured by an accelerometer which is placed on the vehicle.

2. Materials and Method

![Flow Chart of Active Suspension Control System](image)

In order for a vehicle suspension to be ‘active’ there must be exist within the system sensors which detect the orientation of the vehicle and the physical environment on which the vehicle drives upon. In this study however, the sensor used is an accelerometer, there are other sensors that may be used like an Inertia Measuring Unit (IMU), Gyroscope etc. for instance, in the gyroscope sensor there exist an error that occurs as a result of compounding null bias stability as the period of integration increases which causes a seeming rotation even when the device is has zero change in velocity [3].

2.1 Major Components Used
- Accelerometer: An accelerometer is a Micro-Electro-Mechanical Systems, (or MEMS) device that measures the acceleration of forces on an object. An accelerometer in this way, measures the forces applied by restrictions on a reference mass to hold its position (The Editors of Encyclopedia Britannica, 2017). It is a capacitive device, the distance between the adjacent plates causes a change in the voltage across the plates, and this voltage is proportional to the acceleration of the forces acting on the body in the x, y, and z axes. The accelerometer used in this project was the ADXL 335 accelerometer which is a triple axis accelerometer [6].
- Microcontroller: Microcontrollers are programmable electronic devices made up of a Central Processing Unit (CPU), Input-Output ports for receiving and sending out electronic signals, the memory for storing the source code of programs written, timer, Analogue-to-Digital converters and Digital-to-analogue converters. [7] The microcontroller used in this project is the Arduino Mega 2650 board.
- Wheel actuators: these are electromechanical devices with a control system that receives and converts the signals from the microcontroller, in order to change the wheel-travel of the vehicle thereby lifting or lowering the chassis of the vehicle. The wheel actuators used in this project
consisted of a servo motor which used a rack and pinion system to convert its rotary motion to linear motion to raise or lower the vehicle.

2.2 Implementation

An accelerometer measures the acceleration of forces as earlier discussed about a reference mass, the values of these accelerations in the x, y and z-axes can be computed to derive the angle of inclination of each axis of the sensor. From the Figure 1, the accelerometer detects the orientation of the body of the vehicle then sends the value of its measurements to the microcontroller. Note that for this implementation the x-axis is parallel to the longitudinal axis of the vehicle.

Formula

\[
\phi = \tan^{-1} \frac{-A_x}{A_z}
\]

Equation 1

where \( A_x \) is the magnitude of the acceleration measured along the x-axis and \( A_z \) is the magnitude of the acceleration measured along the z-axis of the accelerometer which is equivalent to the acceleration due to gravity.

The microcontroller receives the signals from the accelerometer every millisecond and these values are processed to give the acceleration along each axis and the angle of inclination of the required axis.

As the angles of pitch are determined per time, the wheel actuators which are connected to the output ports of the microcontroller receive electronic signals to either increase or decrease the wheel travel of both the front and rear wheels. The right and left wheels of either front or rear move together and not independently, this is because only the pitching (i.e. nose up or nose down) motion was considered during the active suspension designed during for the tests carried out, however, it is possible to design for a combined motion of the vehicle as the road surfaces are uneven.

With the angle of inclination determined it is possible to determine the height of the bump and determine to what length the wheel-travel of the front and rear wheels must be increased or decreased. The height of the bump can be determined using trigonometry in the Equation 2 below:

\[
h = w \sin \phi
\]

Equation 2

Where \( h \) is the height of the bump, \( w \) is the wheel base (centre-to-centre distance between the front and rear axles) and \( \phi \) is the angle of inclination.

\[\text{Figure 2: Inclination of Vehicle Chassis in Pitch-up Position (arrow A pointing to the front of the vehicle).}\]

Once the height of the bump is determined, the wheel-travel can be changed to counter change in inclination, this change in wheel-travel is shared by the front and rear wheels by an equal amount and in the opposite direction. To counter the rotation caused by a bump of height \( h \) as shown in Figure 2, the front wheel-travel reduces by half the height of the bump thereby lowering the front of the model vehicle and the
rear wheel-travel is increased by half the height \( h \) thereby raising the rear of the vehicle. The reverse is the case for a ditch of depth \( h \). These combined change in wheel-travels caused the chassis of the model vehicle to counter the inclination motion caused by the bump.

The readings from the accelerometer had a lot of noise, in order to reduce the noise and get a smoother curve, the Arduino Sketch was written to find the average of twenty consecutive inputs from the accelerometer, and the average was used to determine the angle of inclination.

3. Results and Discussion

For a vehicle to maintain its leveled position, it must maintain zero vertical acceleration (from Skyhook Theory). The value of this acceleration is measured by an accelerometer. Although the “vertical” acceleration was not directly measured in this project, the acceleration measured is that of the x-axis which is parallel to the longitudinal axis of the vehicle and computed with the acceleration due to gravity (along the Z-axis) measured earlier on a flat horizontal surface in order to determine the angle of inclination of the body of the vehicle.

The active suspension system of this project was designed to correct pitching motion caused by bumps or ditches or slopes on the road surface by causing a forward or backward pitch of the vehicle chassis by concurrently increasing and decreasing the wheel travel.

| Angle of Inclination of Chassis | Acceleration (g) | Height of bump (cm) |
|---------------------------------|------------------|---------------------|
| 10° clockwise                   | 0.20             | +2.90               |
| 0°                              | 0.06             | 0                   |
| 10° anticlockwise               | 0.40             | -2.90               |

From the table above, the values of the acceleration varies with the orientation of the x-axis being measured. With the angle of the inclination derived from the formula stated in the previous section 2, the wheel travel required to compensate the inclination is also determined.

| Height of bump (cm) | Servo position (degrees) | Change in front wheel travel (cm) | Change in rear wheel travel (cm) |
|---------------------|--------------------------|----------------------------------|---------------------------------|
| +2.90               | 105.00                   | -1.44                            | +1.44                           |
| 0(flat surface)     | 90.00                    | 0                                | 0                               |
| -2.90               | 65.00                    | +1.44                            | -1.44                           |

4. Conclusion

In this project, an active suspension was designed to keep the model vehicle leveled during pitching motions (while it moved on an inclined surface). The program for the microcontroller to control the active suspension was developed and uploaded into the same. Tests carried out showed that the suspension was active as there the wheel-travel changed. In this project carried out attention was not given to the other suspension elements which are the springs and dampers.

Although the active suspension did not totally eliminate the pitching motions, it reduced the magnitude of the movement of the chassis of the model vehicle. This was due to:

- the response time of the control system,
- speed of the wheel actuators,
and the stability of the control system as there was a lot of noise.

Accelerometer application in electronically controlled active suspension system is best used for constant velocity vehicles, because the acceleration of the vehicle will be sensed by the accelerometer and interpreted by the microcontroller program as a change in angle of tilt of the vehicle body, in order to eliminate this error other sensors such as gyroscopes or inertia measuring unit must be integrated into the design.

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