LQR Controller for Active Car Suspension

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Abstract: The suspension system is classified as a passive, semi-active, and active suspension, according to its ability to add or extract energy. An automotive active suspension control has been one of the favourite subject in the automotive research area. The advantages of an automotive active suspension system have been promised for many years. The objectives of control scheme are to improve the ride quality and handling performance within a given suspension stroke limitation. The ride quality is measured by the vertical acceleration of the vehicle body called sprung mass. The handling performance is determined by the tyre deflection, which is the difference of position between the wheel and the road surface input.

This paper will analyse the aspects of passive and active suspensions and focus on the ride quality improvement. The LQR control scheme is selected to control an actuator in active suspension. The result shows that the ride quality can be improved using an active suspension.

Keywords
Suspension control system, optimal control.

I. INTRODUCTION

Suspension system is the automotive system that connects the wheels of the automobile to the body, in such that the body is cushioned from jolts resulting from driving on uneven or rough road surfaces. Springs provide cushioning when a wheel hits a bump on the road . A vehicle suspension may be categorised as passive, semi-active and active. Passive suspension system consist of conventional springs and shock absorbers. The springs are assumed to have a linear characteristic and shock absorbers exibit nonlinear relationship between force and velocity. . In passive systems, these elements have fixed characteristics and, hence, have no mechanism for feedback control. The semi-active system changes only the damping coefficient by controlling the electromagnetic valve inside the absorber. The key characteristic of the active suspension system is that an external power source is used to achieve the desired suspension goal. The actuator is placed as a secondary suspension system for the vehicle as in Figure 1. The controller drives the actuator based on the designed control law. The active suspension system provides the freedom to adjust the entire suspension system, and the control force can be introduced locally or globally based on the system state.

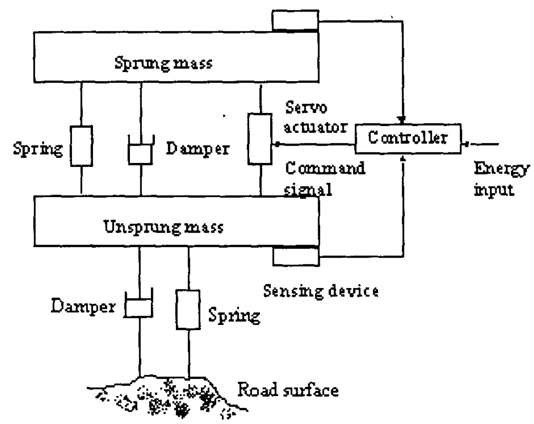

Figure 1 Actuator and sensor configuration in active suspension system.

II. SUSPENSION PERFORMANCE

In any vehicle suspension system, there are variety of performance parameters to be considered. The most important parameters are[1]:

i. Ride comfort; is directly related to the accelaration sensed by passengers when travelling on a rough road.
ii. Body motion; which are known as bounce, pitch and roll of the sprung mass are created primarily by cornering and braking maneuvers.
iii. Road handling; is associated with the contact forces of the tires and the road surface.

iv. Suspension travel; refers to the relative displacement between the sprung and the unsprung masses.

The advantage of controlled suspension is that a better set of design trade-offs are possible compared with passive suspension.
In this study, we are dealing with LQR control for active suspension; however, our intention is not to compare this method with with other control approaches .

III. DYNAMIC MODEL

The two degrees of freedom quarter car model as in figure 2 is the most commonly used model in controller design studies for active suspensions[2]. The equations of motion for the model are found by adding vertical forces on the sprung and unsprung masses. The state equation the active suspension system is represented by

$$\dot{X} = Ax + Bu + G\delta \quad (1)$$

$$\begin{bmatrix} (\dot{z2 - zr}) \\ \ddot{z2} \\ (\dot{z1 - z2}) \\ \ddot{z1} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ \frac{k2}{m2} & \frac{b1}{m2} & \frac{k1}{m2} & \frac{b1}{m2} \\ \frac{b1}{m2} & \frac{k1}{m2} & -\left(\frac{b1+b2}{m2}\right) & \frac{k2}{m2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} z2 - zr \\ \dot{z2} \\ z1 - z2 \\ \dot{z1} \end{bmatrix}$$

$$+ \begin{bmatrix} 0 \\ \frac{m1}{m2} \\ 0 \\ -1 \end{bmatrix} [u] + \begin{bmatrix} -1 \\ \frac{b2}{m2} \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \dot{zr} \end{bmatrix} \quad (2)$$

where the state variables $x_1 = (z_2 - z_r)$, $x_2 = \overset{o}{z_2}$, $x_3 = (z_1 - z_2)$ and $x_4 = \overset{o}{z_1}$ are the tire deflection, unsprung mass velocity, suspension deflection and sprung mass velocity respectively. The control signal is represented by u and road disturbances by $\dot{zr}$. Furthermore, k_1, k_2 and b_1, b_2 are constant parameters for spring and damper respectively.

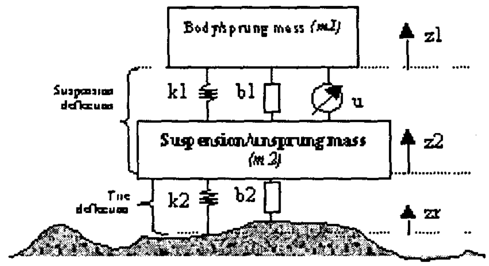

Figure 2 A quarter car model with active suspension.

IV. CONTROLLER DESIGN

The linear time-invariant system (LTI), is described by equation 1. Consider a state variable feedback regulator;

$$\mathbf{u} = -\mathbf{Kx} \quad (3)$$

where **K** is state feedback gain matrix.
The optimization procedure consists of determining the control input **u**, which minimizes the performance index. The performance index **J** represents the performance characteristic requirement as well as the controller input limitation. The optimal controller of given system is defined as controller design which minimizes the following performance index[3].

$$\mathbf{J} = \int_0^\infty (\mathbf{x'Qx} + \mathbf{u'Ru})\mathbf{dt} \quad (4)$$

The matrix gain K is represented by;

$$\mathbf{K = R^{-1}B'P} \quad (5)$$

The matrix P must satisfy the reduced-matrix Riccati equation.

$$\mathbf{A'P + PA - PBR^{-1} B'P + Q = 0} \quad (6)$$

Then the feed back regulator

$$\mathbf{U = -(R^{-1}B'P)x} \quad (7)$$

V. SIMULATION RESULT

Simulation task is performed using a Matlab software. By considering vehicle hit a cusp and traveling along the bumping road, simulation is carried out using the step-input signal and random input signal respectively[4]. Figure 3 and Figure 4 show the simulation results for both test signals.

VI. CONCLUSION

The simulation result shows that an active suspension gives a better performance in terms of comfort ride compared to the passive suspension. An active suspension also increase a tire-to road contact in order to make the vehicle more stable. In conclusion, from the simulation result, active suspension with LQR controller can be considered one of the solutions for excellent comfort ride and good handling of cars in the new millennium.

VII. REFERENCES

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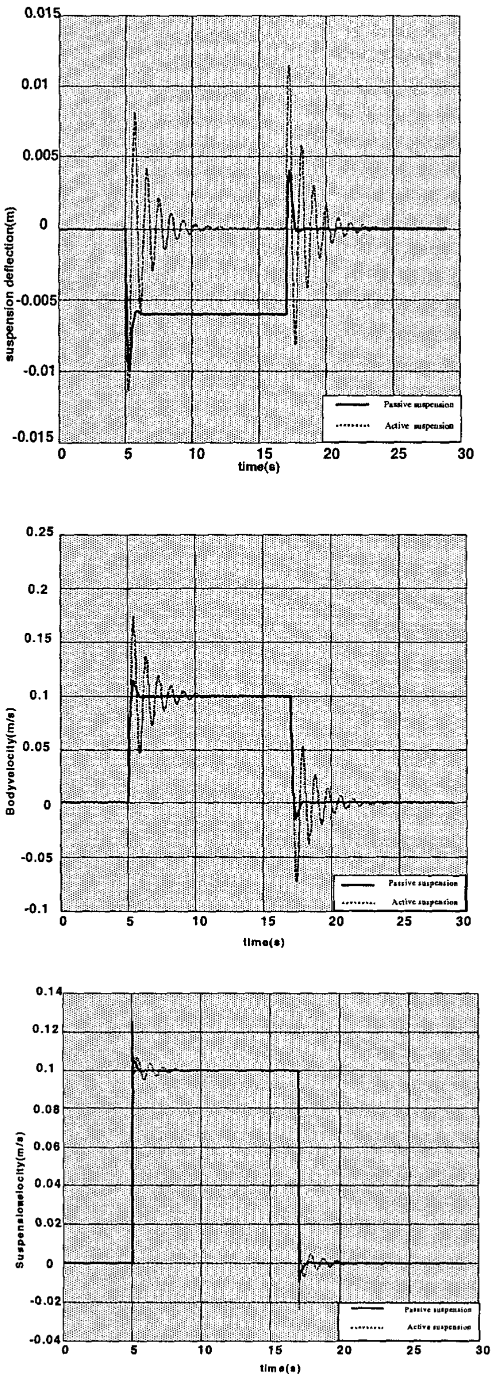

Figure 3: Suspension deflection, Body Velocity and Suspension Velovity with step input

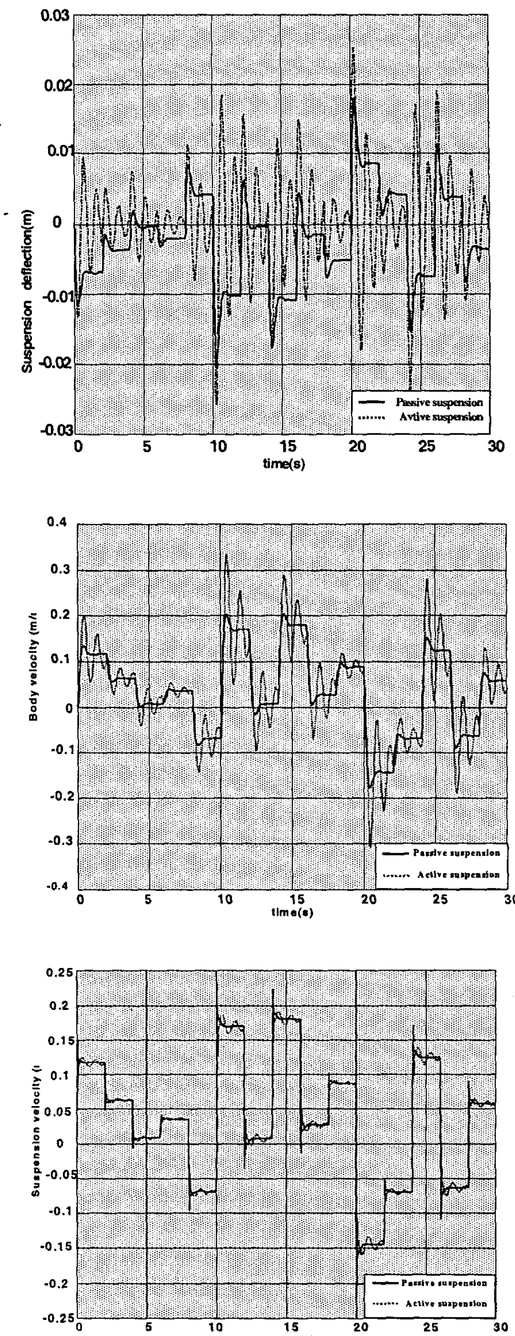

Figure 4: Suspension deflection, Body Velocity and Suspension Velovity with random input