CONTROL AN ACTIVE SUSPENSION SYSTEM BY USING PID AND LQR CONTROLLER

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ABSTRACT

The suspension has a very important effect on the comfort and stability of the vehicle on the move. To improve safety issues as well as comfort and convenience, the active suspension system is used to replace the conventional mechanical suspension system (passive suspension system). There are many controllers used to control the active suspension system such as PID controller, LQG controller, LPV controller. This research focuses on analyzing, evaluating, comparing, and applying two controllers: PID controller and LQR controller for an active suspension system. The results of the research have shown that when the vehicle is equipped with an active suspension system, the values of displacement and acceleration of the sprung mass are significantly improved. Besides, the PID controller supports to optimize the body's acceleration, the LQR controller supports to optimize the body's displacement. This research will be the basis for supporting more complex researches in the future.

KEYWORDS: Active Suspension System, PID Controller, LQR Controller, Dynamic Vehicle Model

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INTRODUCTION

The suspension system of the vehicle is the soft link between the wheel and the body. The suspension system is capable of regulating and quenching vibrations from the road surface. Besides, the suspension system supports the stability of the vehicle in the case of steering or turning around [1-4]. The conventional mechanical suspension system (passive suspension system) can't meet the problems of the comfort and stability of the vehicle when moving. Therefore, the active suspension system has been used to replace the passive suspension system. The active suspension system is equipped with a hydraulic actuator between the sprung mass and the un-sprung mass. This system is automatically controlled via ECU and sensors [5, 6]. When the vehicle goes through a bumpy road, the sensor will record information about the acceleration of the vehicle's body. This information is then sent to the ECU controller. Here, the ECU will analyze, evaluate, and send the current signal $i(t)$ to the actuator. The actuator (hydraulic piston-cylinder assembly) will produce FA thrust acting on the sprung mass and the un-sprung mass. Therefore, the comfort of the vehicle can be improved. However, due to the complicated control process and the high price, the active suspension system is only used on high-class models.

In recent years, there have been many studies on optimizing the comfort of the suspension system [7-10]. Besides, articles regarding the control active suspension system have also been published. In these studies, the most commonly used control methods are PID, LQG, LPV, Fuzzy Logic,... [11-35]. In general, the results of the above articles show the advantages of the active suspension system compared to the conventional passive suspension system. Each control method will have its advantages and disadvantages, corresponding to the vehicle's moving conditions.

This research focuses on modeling the active suspension control process using the PID controller and the LQR controller. The parameters of these two controllers were calculated and optimized to achieve the highest results.

CONTROL MODEL

Dynamic Vehicle Model

As usual, the dynamic quarter vehicle model of the vehicle is used in the studies of control and optimization of the comfort of the suspension system.

The dynamic quarter vehicle model of the vehicle is given as shown in Figure 1

Figure 1: Dynamic Quarter Vehicle Model.

The equations describing the oscillation of the vehicle are shown as follows:

$$M\ddot{z} = F_K + F_C + F_A \quad (2.1)$$

$$m\ddot{\xi} = F_{KT} - F_K - F_C - F_A \quad (2.2)$$

Where

$$F_K = K(\xi - z) \quad (2.3)$$

$$F_C = C(\dot{\xi} - \dot{z}) \quad (2.4)$$

$$F_{KT} = K_T(u - \xi) \quad (2.5)$$

PID Controller

PID controllers are commonly used in the field of industrial control. This controller has the advantage of being simple, compact, durable, and low cost. However, the PID controller can only receive a single-input. Therefore, complex models can't use the PID controller.

The diagram of the PID controller is shown in Figure 2. The signal $e(t)$ after going into the PID controller will be processed by 3 algorithms:

+ Proportion algorithm: $K_p e(t)$

+ Integrationalgorithm: $K_i \int_0^t e(\tau) d\tau$

+ Derivationalgorithm: $K_d \frac{de(t)}{dt}$

Figure 2: PID Controller Schematic.

LQR Controller

The LQR controller (Linear Quadratic Regulator) is the optimal controller. This controller can use the multi-input parameters of the pre defined model. To obtain the output signal $i(t)$, the coefficient R needs to be calculated.

Figure 3: LQR Controller Schematic.

Let's Q is the cost function:

$$Q = \frac{1}{2} \int_0^{\infty} x^T (C + R^T D R) x dt = \frac{1}{2} \int_0^{\infty} x^T K x dt \quad (2.6)$$

Through (2.6) can easily identify R .

The equations established in section 2.1 can transform into the following matrix form:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) \\ y(t) = Cx(t) + Du(t) \end{cases} \quad (2.7)$$

The matrix A is a state matrix, matrix B is an input matrix, matrix C is an output matrix, and matrix D is a navigation matrix.

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{K}{M} & \frac{K}{M} & -\frac{C}{M} & \frac{C}{M} \\ \frac{K}{m} & -\frac{(K+K_T)}{m} & \frac{C}{m} & -\frac{C}{m} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_T}{m} \end{bmatrix}$$

$$C = \begin{bmatrix} c_{11} & 0 & 0 & 0 \\ 0 & c_{22} & 0 & 0 \\ 0 & 0 & c_{33} & 0 \\ 0 & 0 & 0 & c_{44} \end{bmatrix} \quad D = [d_{11}]$$

RESULTS

The research used reference parameters as shown in Table 3.1.

Table 1: Vehicle Specifications

Symbol	Description	Value	Unit
M	Sprung mass	350	kg
m	Un-sprung mass	50	kg
C	Damping coefficient	3000	Ns/m
K	Stiffness of the spring	35000	N/m
K _T	Stiffness of the tire	100000	N/m

The excitation signal from the road surface $u(t)$ is shown in the following two cases:

$$+ \text{Case 1: } u(t) = \begin{cases} 0, t < 0 \\ 0.05, 1 \leq t \leq 2 \\ 0, t > 2 \end{cases}$$

$$+ \text{Case 2: } u(t) = \begin{cases} 0, t < 1 \\ 0.05, t \geq 1 \end{cases}$$

For each case, the values of displacement and acceleration of the vehicle's body will be compared.

Case 1

The displacement of sprung mass is described as shown in Figure 4. If the vehicle only uses a passive suspension system, the value of the displacement of the sprung mass will be very large, $z_{\max} = 78.5$ (mm). If the vehicle is equipped with an

active suspension system, this value can be significantly reduced. The maximum value of the displacement $z_{\max}$ corresponding to the LQR controller and the PID controller is 44.9 (mm) and 60.1 (mm), respectively.

Figure 4: Displacement of the Sprung Mass.

The acceleration of the sprung mass also varies greatly when the vehicle is equipped with an active suspension system. These values are maximized at $9.1 \text{ (m/s}^2\text{)}$, $5.7 \text{ (m/s}^2\text{)}$ and $4.0 \text{ (m/s}^2\text{)}$, respectively, in the case non controller, LQR controller, and PID controller.

Figure 5: Acceleration of the Sprung Mass.

Case 2

Figure 6 describes the displacement of the sprung mass in case 2. In general, if the vehicle is not equipped with an active suspension system, the value of $z_{\max}$ will be very large and fluctuate continuously for approximately 3(s). If the vehicle uses an active suspension system with the PID controller, the amplitude of oscillation will be much smaller. However, if replacing the PID controller with the LQR controller, the amplitude and frequency of oscillation are almost clearly optimized.

Figure 6: Displacement of the Sprung Mass.

The acceleration of the sprung mass also varies greatly when the vehicle is equipped with the active suspension system (Figure 7). The acceleration of the sprung mass when using the PID controller has a smaller amplitude than that of the LQR controller. However, its oscillation frequency is larger.

Figure 7: Acceleration of the Sprung Mass.

CONCLUSIONS

The suspension ensures the comfort and stability of the vehicle when moving on the road. However, the conventional mechanical suspension system (passive suspension system) can't solve the problem posed to vehicles. Therefore, the active suspension system is used instead.

The active suspension system is controlled automatically, quickly, and accurately. The main methods used to control this suspension are PID, LQR, LQG, LPV, FuzzyLogic, ...

This research focused on the analysis, evaluation, and application of two the active suspension system controllers: PID Controller and LQR Controller. Overall, when the vehicle is equipped with an active suspension system, the comfort and stability of the vehicle can be significantly improved. The PID controller supports to optimize the acceleration of the

sprung mass. On the other hand, the LQR controller supports to optimize the displacement of the sprung mass. Therefore, the limit of the oscillation needs to be pre defined to select the appropriate controller.

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