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Research Article

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Improving Stability of a Vehicle through Active Suspension System using Genetic Algorithm

Godwin Ozor, Erasmus Ozioko, Francis Okoye

Computer Engineering, Enugu State University of Science and Technology, Nigeria

Abstract The viability of an active suspension system of a vehicle is tested based on the ride comfort and road handling. Active suspension system is the conventional suspension system of a vehicle with a parallel connected force actuator. In this paper, the transfer function of the plant (suspension system) was modelled. The PID (proportional, integral, derivative) controller was automatically tuned with genetic algorithm for real-time convergence. The rise time and settling time were investigated in this research. The results showed minimal suspension travel and sustainable stability as it was compared with conventional suspension system.

Keywords Stability, genetic algorithm, PID, active suspension, convergence

1. Introduction

Crosby and Karnopp's article titled "The Active Damper" dating from the mid-1970s [1] was one of the earliest papers on the electronic control of suspension systems. However, even as late as 1995, Karnopp noted that, "It is probably no surprise in retrospect that progress on practical active vibration control systems has been relatively slow. The design of such systems requires a clear concept, related not only to the mechanics of the system but also to automatic control and system dynamics. Sensors and actuators must be available and their limitations considered and finally cost effective signal processing devices must be available. Only relatively recently has progress in all these aspects come to the point at which practical designs are possible." Since the mid-1990s the landscape has changed dramatically and sensors and actuators have become inexpensive, fast and reliable, to the point that they are now regularly installed in production vehicles. The actuators are allowed to improve the passenger comfort because this element is placed in parallel with the damper and the spring between the unsprung mass and the sprung mass [2]. While electronically-controlled suspensions are available mainly in more expensive vehicles, their use is steadily expanding.

The importance of suspension system in automobile made it possible for many researchers to work in different aspect of it, just to improve comfort and road holding or stability. Wang D, *et al* [3], used model predictive control with fractional PID controller to optimize the gains.

Genetic algorithms (GAs) are computer algorithms that can be used to evolve engineering systems, making slight changes to design parameters and selecting improvements based on performance. This is an iterative process that mirrors biological evolution, employing computer analogues of biological reproduction, cross-breeding, and selection. It requires a great deal of computer processing power, but it has proven successful over a wide range of engineering applications.

Free movement within the vertical travel does not of itself adversely affect a suspension. When the wheel is moving over rough, small corrugations like pot holes, bumps and non-asphalt roads, the suspension comfort as well as road normal force are improved if the chassis remains relatively flat irrespective of tire contact angle with the road. With the chassis remaining flat or fairly stable, the wheel must move up and down to match the road corrugations, with corresponding suspension displacement movement. Brezas and Smith [4] modelled a time-domain optimal control using quarter car and full-car models of active suspensions, which they incorporated road disturbances and a representation of driver input. But this suspension movement does not of itself adversely affect comfort, and may well improve road holding. Control systems such as active suspension system is useful in improving the ride comfort and road handing as proposed by Cao. M, *et al* [5]. A suspension should be able to move freely within the vertical travel to optimize comfort, but at the same time minimize the chance of hitting unnecessarily against the vertical travel limits.Ride comfort has become one of the important criteria in a vehicle. Isolating the passenger compartment from the vibration sources is the main idea in achieving a good ride comfort. This role is mainly covered by the suspension system of a car. Conventional suspension system has fix criteria of spring and damping coefficient usually cannot give the best ride comfort as the road profile is different depending on area. A novel approach to classify road excitations based on measurable suspension system response was proposed by [6]. Besides, it is also subjected to the needs of maintaining the handling as the suspension system also plays a main role on vehicle stability. Thus, this conventional passive suspension system is usually designed based on certain criteria of the vehicle which the suspension will be installed. The basic part of a passive suspension system is a damper and a coil spring.

2. Quarter Car Active Suspension System (ASS) Dynamics

A. Two Degree of Freedom (2DOF) ASS Model

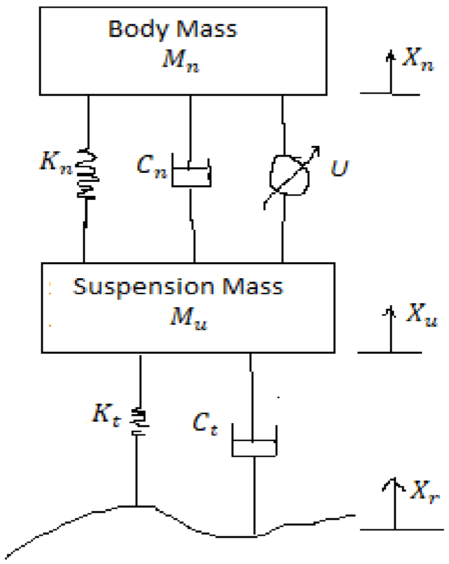

Figure 1: Quarter car active suspension model

The Fig. 1 shows the vertical unsprung mass and the vertical motion of the mass. The suspension system parameter as indicated in the model are shown in Table 1.

Table 1: Parameters of active suspension model

Symbol	Description
M_n	car chassis mass
M_u	wheel mass
K_n	spring constant of suspension system
K_t	spring constant of wheel and tire
C_n	damping constant of suspension system
C_t	damping constant of wheel and tire
U	actuator force
X_n	body displacement
X_u	wheel displacement
X_r	road profile

From the diagram in Fig. 1 and Newton's law, dynamic equations of the quarter car active suspension system.
Equation Spring mass

$$M_n\ddot{X}_n + K_n(X_n - X_u) + C_n(\dot{X}_n - \dot{X}_u) - U = 0 \quad (1)$$

Hence

$$M_n\ddot{X}_n = -K_n(X_n - X_u) - C_n(\dot{X}_n - \dot{X}_u) + U \quad (2)$$

Equation unspring mass

$$M_u\ddot{X}_u + K_t(X_u - X_r) + C_t(\dot{X}_u - \dot{X}_r) - K_n(X_n - X_u) - C_n(\dot{X}_n - \dot{X}_u) + U = 0 \quad (3)$$

Hence

$$M_u\ddot{X}_u = -K_t(X_u - X_r) - C_t(\dot{X}_u - \dot{X}_r) + K_n(X_n - X_u) + C_n(\dot{X}_n - \dot{X}_u) - U \quad (4)$$

B. **Transfer Function Model**

The proposed model, assumes that all the initial conditions are zero. The dynamic equations above will be expressed in the form of transfer functions of the system by taking the Laplace transform. The specific derivation from the above equations to the transfer functions $G_1(s)$ and $G_2(s)$ is shown below where each transfer function has an output of $X_n - X_u$ and inputs of U and X_r respectively.

$$(M_n s^2 + C_n s + K_n)X_n(s) - (C_n s + K_n)X_u(s) = U(s) \quad (5)$$

$$-(C_n s + K_n)X_n(s) + \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right)X_t(s) = (C_t s + K_t)X_r(s) - U(s) \quad (6)$$

Arranging equations (5 and 6) in matrix format

$$\begin{bmatrix} (M_n s^2 + C_n s + k_n) & -(C_n s + K_n) \\ -(C_n s + K_n) & \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right) \end{bmatrix} \begin{bmatrix} X_n(s) \\ X_u(s) \end{bmatrix} = \begin{bmatrix} U(s) \\ (C_t s + K_t)X_r(s) - U(s) \end{bmatrix} \quad (7)$$

$$A = \begin{bmatrix} (M_n s^2 + C_n s + k_n) & -(C_n s + K_n) \\ -(C_n s + K_n) & \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right) \end{bmatrix} \quad (8)$$

$$\Delta = det\begin{bmatrix} (M_n s^2 + C_n s + k_n) & -(C_n s + K_n) \\ -(C_n s + K_n) & \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right) \end{bmatrix} \quad (9)$$

Or

$$\Delta = (M_n s^2 + C_n s + k_n) * \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right) - (C_n s + K_n)^2 \quad (10)$$

$$\begin{bmatrix} X_n(s) \\ X_u(s) \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} \left(M_u s^2 + (C_n + C_t)s + (K_n + K_t)\right) & (C_n s + K_n) \\ (C_n s + K_n) & (M_n s^2 + C_n s + k_n) \end{bmatrix} \begin{bmatrix} U(s) \\ (C_t s + K_t)X_r(s) - U(s) \end{bmatrix} \quad (11)$$

$$\begin{bmatrix} X_n(s) \\ X_u(s) \end{bmatrix} = \frac{1}{\Delta}\begin{bmatrix} M_u s^2 + C_t s + K_t & (C_n C_t s^2 + (C_n K_t + C_t K_n)s + K_n K_t) \\ -M_n s^2 & (M_n C_t s^3 + (M_n K_t + C_n C_t)s^2 + (C_n K_t + C_t K_n)s + K_n K_t \end{bmatrix} \begin{bmatrix} U(s) \\ X_r(s) \end{bmatrix} \quad (12)$$

When control input $U(s)$ was considered, the $X_r(s)$ was set to zero , $X_r(s) = 0$ and then the transfer function $G_1(s)$ is as follows:

$$G_1(s) = \frac{X_n(s) - X_u(s)}{U(s)} = \frac{(M_n + M_u)s^2 + C_t s + K_t}{\Delta} \quad (13)$$

As road disturbance input $X_r(s)$ was considered, the control input was set to zero, $(s) = 0$, then the transfer function $G_2(s)$ is as follows:

$$G_2(s) = \frac{X_n(s) - X_u(s)}{X_r(s)} = \frac{-(M_n C_t)s^3 - M_n K_t s^2}{\Delta} \quad (14)$$

The transfer function of the active suspension system of the quarter car has been modelled and ready for a controller that will drive the plant (active suspension system). The controller considered for this research work is PID (Proportional, Integral and Derivative). In section III, the transfer function of the PID controller would be modelled.

3. PID Controller

PID controller is the most common in all industries, as it has significant features like easy implementation and simple construction. The PID controller consists of three modes, namely the proportional, integral and derivative modes. Based on the input of the controller, it generates appropriate control output signal to keep the power system response within the specified limit. The transfer function of a PID controller is as shown below

$$G_0(s) = K_p + \frac{K_i}{s} + K_d s \quad (15)$$

Where K_p, K_i and K_d are the proportional, integral and derivative gains of the controller respectively.

The block diagram reduction technique was applied to concatenate the forward gain transfer function of the whole active suspension system.

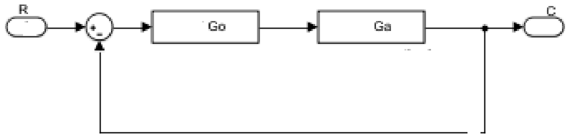

Figure 2: PID control of a suspension System

As the $G_0(s)$ represents the PID controller gain and $G_a(s)$ represents the suspension system plant.

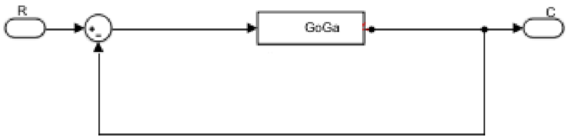

Figure 3: Reduce forward gain with unity feedback

In this paper, the parameters of the PID controller's gain values are optimized by using bio-inspired optimization algorithm, namely Genetic Algorithm (GA).

4. Genetic algorithm

Genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process of biological evolution. The overall transfer function of the active suspension system of a quarter car has been modelled, then the tuning of the PID controller using genetic algorithm to generate the control laws of the system. MATLAB was used to develop the parameter tuning for effective optimization and real time convergence. Rise time, overshoot and settling time were also investigated.

5. PID Controller Tuning using Genetic Algorithm

The numerical values for the quarter-car suspension, presented in Rao, T.R., & Anusha, P [7] and the control parameters are shown in table 2.

Table 2: System parameter values

Symbol	Value	Unit
M_n	2050	Kg
M_u	100	Kg
K_n	100000	N/m
K_t	400000	N/m
C_n	6000	Ns/m
C_t	5000	Ns/m

6. Simulations and Results

The step response of the system in fig 4 shows the unbalanced nature of the proportional, integral and derivative. The overshoot was high which affected the settling time of the system. The steady state error of the function in was marginal above normal range.

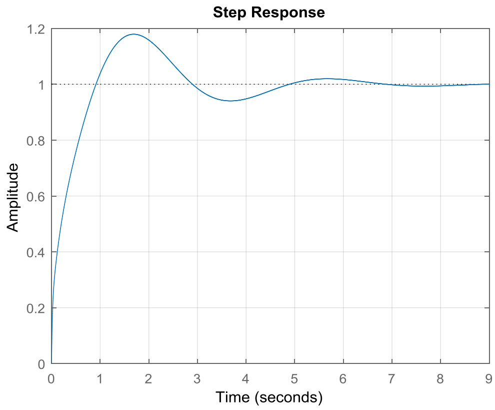

Figure 4: Unstable sytem

The genetic algorithm tuned PID optimized suspension system as indicated in fig 5 shows the best fit of the PID controllers parameters for real time convergence of the system.

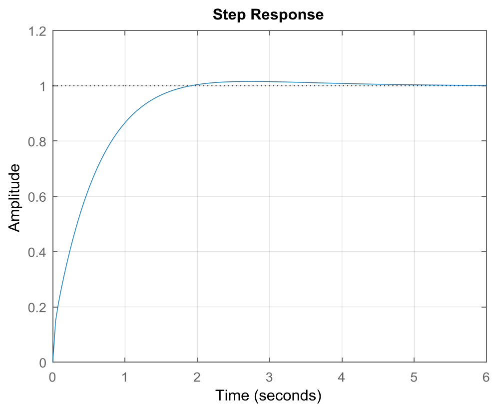

Figure 5: Optimized stable system

7. Conclusion

It was observed that with the values of the PID controllers' parameters as tuned with genetic algorithm improved passenger comfort and road handling. The managed oscillation of the system indicates vertical travel control. The results were compared with conventional (passive) suspension system but significant improvement was noticed in the area stability of the system.

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