DEVELOPMENT OF ACTIVE SUSPENSION SYSTEM FOR CAR USING FUZZY LOGIC CONTROLLER, PID & GENETICALLY OPTIMIZE PID CONTROLLER

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ABSTRACT : *In this paper, develop fuzzy logic controller to control active suspension system to minimize car body deflection. Also develop PID controller to control Active suspension system, also tune gain of PID controller using Genetic algorithm. By using all three methods, vehicle body deflection has been obtained & compare with each others. These comparisons display efficiency of FLC & GA-PID controller method.*

KEY WORDS: Active suspension system, fuzzy logic controller, PID controller, Genetic algorithm, quarter-car reference model.

1. INTRODUCTION

Suspension systems are the most important part of the vehicle affecting the ride comfort of passengers and road holding capacity of the vehicle, which is crucial for the safety of the ride. Designing a good suspension system with optimum vibration performance under different road conditions is an important task. Over the years, both passive and active suspension systems have been proposed to optimize the vehicle quality. Passive suspension [3]
Systems use conventional dampers to absorb vibration energy and do not require extra power. Whereas, active suspension systems capable of producing an improved ride quality use additional power to provide a response-dependent damper[2].
In active suspension systems, an actuator (linear motor, hydraulic cylinder, etc.) parallel to the suspension systems is placed between the wheel and the vehicle body. The actuator uses the suspension space while pulling down or pushing up the vehicle body in order to suppress its vibrations due to the road irregularities.
The primary performance of a suspension system is traditionally evaluated in terms of ride quality. The two principal variables for the design and evaluation of the suspension systems are vehicle body acceleration, which determines ride comfort, and suspension deflection, which indicates the limit of the vehicle body motion.
For the design of active suspension systems for quarter car models, the use of FLC and PID method has been proposed, with a satisfactory performance, applied genetic algorithm to vehicle suspension design, in which the road surface is assumed to be a white noise function.
The main objective of this paper is to propose a new active suspension system for passenger cars, using suspension deflection of the vehicle body as the principal criterion of control, and fuzzy logic & PID control as the complementary. Gains of PID controller are optimizing by genetic algorithm method to minimize vehicle body deflection.

2. MODEL AND DESIGN OF QUARTER-CAR SUSPENSION MODEL.

A.. Structure of mathematical model of 1/4 active suspension[1]

To study the Active control of the vehicle suspension, a two-DOF vehicle dynamic model established as shown in fig.1

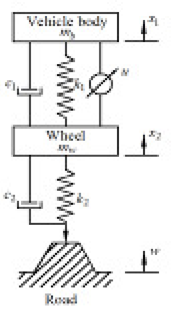


Fig.1. One quarter car model

In the figure
mb=mass of vehicle body
mw=wheel mass
k1=spring stiffness constant of suspension spring
k2= spring stiffness constant of tire
c1= damping coefficient of the suspension systems damper
c2= damping coefficient of the tire
u=desired force by cylinder
x1 is body displacement, *x2* is wheel displacement, *w* is road input

B. State equation of the mathematical model

As it can be seen from the Figure 1 the model has two degrees of freedom. This model uses an actuator to produce the control force between the vehicle body mass and the wheel mass. The equations of motion of the car body and wheel according to Newton's second low are as follows[4]:

$mb\ddot{x}1=-c1\ (\dot{x}1-\dot{x}2)-k1(x1x2)+u$……….. (1)

$mw\ddot{x}2=c1\ (\dot{x}1-\dot{x}2)+k1(x1-x2)+c2\ (\dot{w}-\dot{x}2)+k2\ (w-x2)-u$... (2)

In this calculation parameters *mb, mw, k1, k2, c1* and *c2* are 2500 kg, 320 kg, 80000 N/m, 500000 N/m, 350 Ns/m and 15020 Ns/m, respectively[1].

When a car meets to any obstacle during riding, resulting vibrations must be certainly dissipated in a short period of time. As the system output, the suspension deflection *x1-x2* is chosen. Road surface w, fig 1 can be accepted as white noise input[2].

C. Simulation model of Car suspension system.

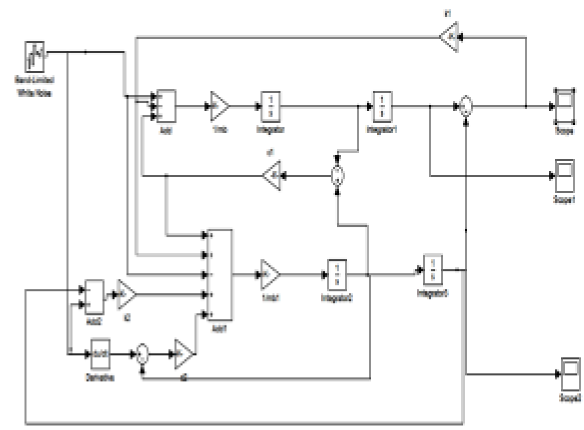


Fig. 2simulation model of un-control suspension system

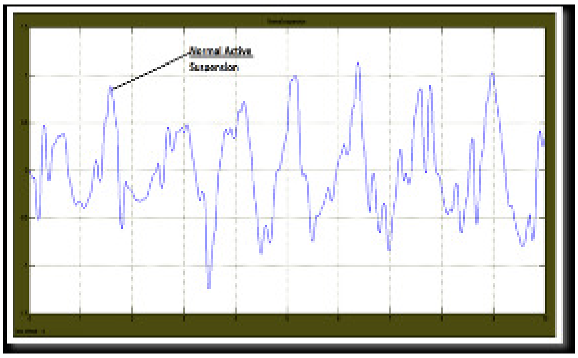


Fig.3 o/p of un-control active suspension system

Body deflection is between 1.5 to -1.5.

3. DEVELOP FUZZY LOGIC CONTROL (FLC) ACTIVE SUSPENSION

This system has 3 inputs and one output

Inputs:
$\ddot{x}1$ = body acceleration,
$\dot{x}1$ = body velocity,
$\dot{x}1-\dot{x}2$ = body deflection velocity,

Output: *u* = actuator force

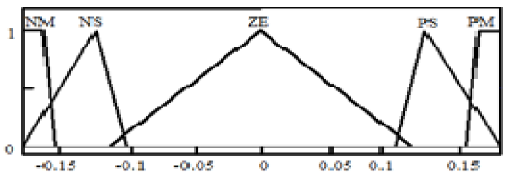
The control system itself consists of three stages: fuzzification, fuzzy inference machine and defuzzification. The fuzzification stage converts real-number (crisp) input values into fuzzy values, while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage.

Rule Base

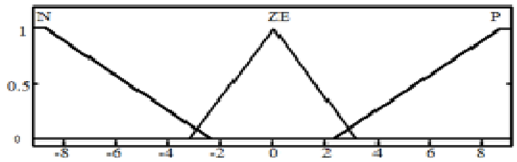
$\dot{x}_1-\dot{x}_2$	$\dot{x}_1$	$\ddot{x}_1$	u	$\dot{x}_1-\dot{x}_2$	$\dot{x}_1$	$\ddot{x}_1$	u
PM	PM	ZE	ZE	PM	PM	P or N	NS
PS	PM	ZE	NS	PS	PM	P or N	NM
ZE	PM	ZE	NM	ZE	PM	P or N	NB
NS	PM	ZE	NM	NS	PM	P or N	NB
NM	PM	ZE	NB	NM	PM	P or N	NV
PM	PS	ZE	ZE	PM	PS	P or N	NS
PS	PS	ZE	NS	PS	PS	P or N	NM
ZE	PS	ZE	NS	ZE	PS	P or N	NM
NS	PS	ZE	NM	NS	PS	P or N	NB
NM	PS	ZE	NM	NM	PS	P or N	NB
PM	ZE	ZE	PS	PM	ZE	P or N	PM
PS	ZE	ZE	ZE	PS	ZE	P or N	PS
ZE	ZE	ZE	ZE	ZE	ZE	P or N	ZE
NS	ZE	ZE	ZE	NS	ZE	P or N	NS
NM	ZE	ZE	NS	NM	ZE	P or N	NM
PM	NS	ZE	PM	PM	NS	P or N	PB
PS	NS	ZE	PM	PS	NS	P or N	PB
ZE	NS	ZE	PS	ZE	NS	P or N	PM
NS	NS	ZE	PS	NS	NS	P or N	PM
NM	NS	ZE	ZE	NM	NS	P or N	PS
PM	NM	ZE	PB	PM	NM	P or N	PV
PS	NM	ZE	PM	PS	NM	P or N	PB
ZE	NM	ZE	PM	ZE	NM	P or N	PB
NS	NM	ZE	PS	NS	NM	P or N	PB
NM	NM	ZE	ZE	NM	NM	P or N	PS

Table 1.Rule base of FLC model

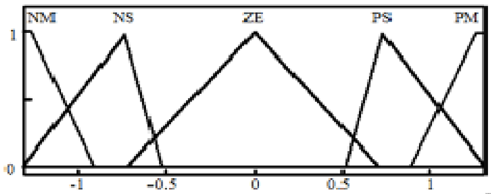
Membership function is
[NV NB NM NS ZE PS PM PB PV]
NV=negative very big
NB=negative big
NM=negative medium
NS=negative small
ZE=zero
PS=positive small
PM=positive medium
PB=positive big
PV=positive very big



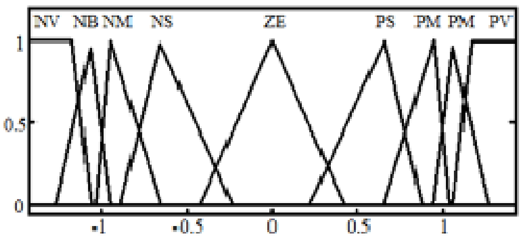
(a) Body deflection velocity



(b) Body acceleration



(c) Body velocity



(d) Desire acturer force

Fig.4 membership function

4. SIMULATION MODEL OF FLC ACTIVE SUSPENSION SYSTEM

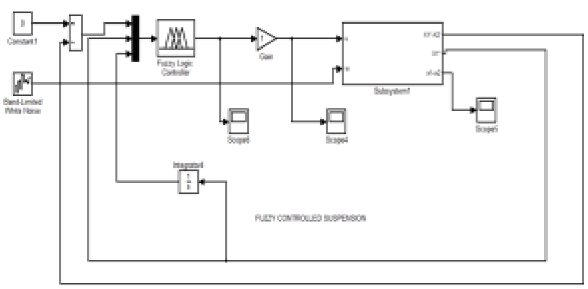


Fig.5 Simulation of FLC model

This Simulink model is used in a FLC model with a feed back control system modelled by the Matlab Fuzzy Logic Toolbox. The block diagram of the FLC model is depicted in Figure 5.

In this model, body deflection velocity $\dot{x}_1$-$\dot{x}_2$, body velocity $\dot{x}_1$ and body acceleration $\ddot{x}_1$ are taken as the feedback inputs, whereas desired actuator force (u) is the output of the fuzzy logic controller.

The input of the fuzzy logic Simulink model is white noise block which produces 4 to -4 cm displacement initially, for road surface roughness. Body deflection which is the output of the model can be traced by means of the scope block until the end of the simulation time.

Simulation result shown in figure 6

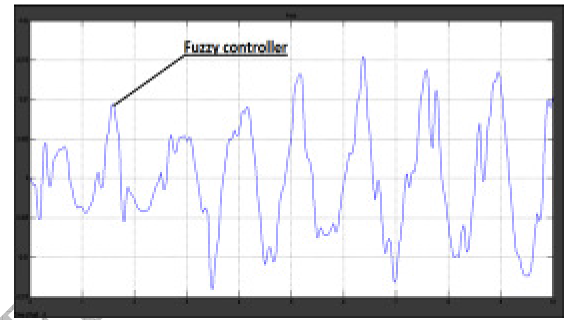


Fig.6 result of FLC controlled suspension system

From the result we clear show that with the use of Fuzzy logic controller body displacement is reduce to 0.015 to -0.015.

5. CAR SUSPENSION SYSTEMS DESIGNED WITH PID CONTROLLER

The PID controllers (in which P, I and D stand for proportional, integral and derivative, respectively) have been used to control various engineering systems such as suspensions, and DC motors. In this study, the results of the FLC & GA-PID are going to be compared with those of PID controller.

Consequently, firstly, the PID controller is introduced. In this control method, with the aid of the Laplace transform, two transfer functions are derived. As known, the Laplace transform is one of the mathematical tools used for the solution of linear ordinary differential equations. In comparison with classical linear differential equation solving techniques, the Laplace transform has a simple construction. Utilizing the Laplace transform, the transfer function G1(s) and G2(s) are derived from the equation of motions *(Eq (1) & Eq (2))* as following[13]

$$G_1(s) = \frac{x_1(s) - x_2(s)}{u(s)} = \frac{(m_b + m_w)s^2 + c_2 s + k_2}{\Delta}$$

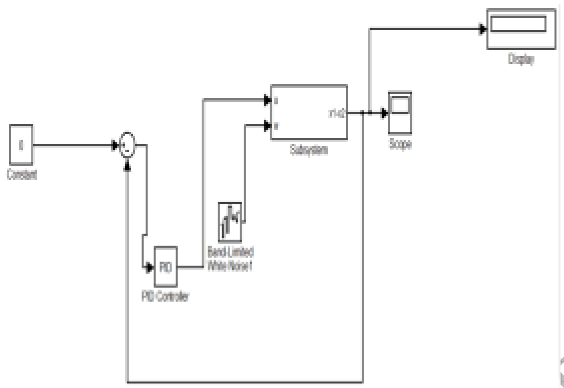
$$G_2(s) = \frac{x_1(s) - x_2(s)}{w(s)} = \frac{-m_b c_2 s^3 - m_b k_2 s^2}{\Delta}$$

Where

$$\Delta = \det\begin{bmatrix} (m_b s^2 + c_1 s + k_1) & -(c_1 s + k_1) \\ -(c_1 s + k_1) & (m_w s^2 + (c_1 + c_2)s + (k_1 + k_2)) \end{bmatrix}$$

The PID controller simulation diagram is shown in fig 8. In which u and w are system inputs and *x1-x2* is the system output.

This block diagram has a closed loop structure. The loop begins the control, with zero



initial value of r = 0 and an assigned value of w. Then, it takes the difference of the obtained system input value and the first initial value as new initial condition. The other calculations are performed by the procedure given before. When the design requirements are satisfied, it stops the calculation.[10]

Fig. 7 PID controlled simulation model

Taking into account the proportional gain *Kp,* integral gain *Ki,* and derivative gain *Kd* in the transfer function expressions of *G1(s)* and *G2(s),* the general equation of PID control is obtained as follows[11]:

$$K_p + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_p s + K_I}{s}$$

The values of gains determined by the "root curve seat method" are explained in reference (Bingöl, 2005). Taking the values for *mb, mw, k1, k2, c1* and *c2* as stated in section 2, the root curve seat method gives, for a good controller, 1664200, 1248150 and 416050 values for *Kp, Ki* and *Kd* gains, respectively[14].

Figure 7 shows the PID controller Simulink model of the considered car suspension system.

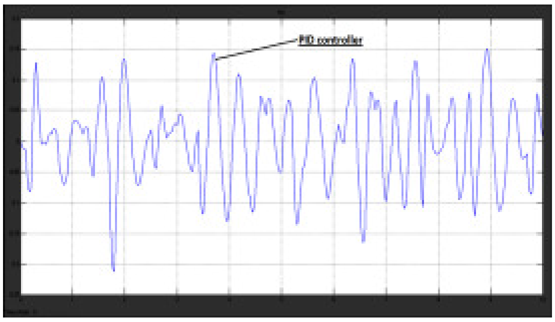


Fig.8 Result of PID controlled suspension

6. GA-PID CONTROLLER FOR SUSPENSION SYSTEM

Genetic algorithms (GAs) are randomized search techniques guided by the principles of evolution and natural genetics. They are effective, adaptive and robust search procedures, producing near global optimal solutions and having a large amount of implicit parallelism. This method has been widely used by researchers and has been successfully applied to various problems[8].

Gain of PID controller is optimizing by using GA tools. In this method we use Previous PID simulation model result. From this we set upper & lower limits in GA toolbox.

Hear main objective function is Body Deflection error e (t).

So our fitness function is

$$norm\left(\frac{d^2(e(t))}{dt^2}\right) + 50norm(e(t))$$

- GA was run in the following steps
  - First made .m file for fitness function.
  - Then define variable(in our case we find *Kp, Ki, & Kd* so variable is 3)
  - Then define lower & upper Bounds.
  - Set population size.
  - Fitness scaling function.
  - Set selecting function.
  - And other variable value takes default.

Run GA tool at population 20 values of *Kp, Ki, Kd* are 8050595, 9837175, 2238106.

And for population 30 9267494, 9837117, 4085205 put this value in simulation of PID controller we get much better result than normal PID controller

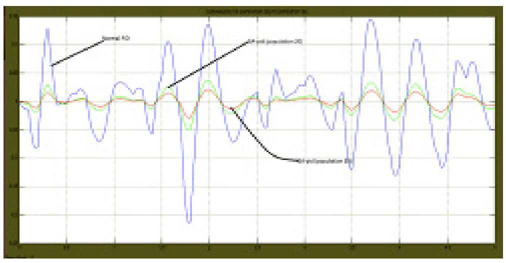


Fig.9 GA-PID result

Result yellow line shoe the o/p of normal PID controller, pink & sky-blue line show the output of GA-PID controller for population 20 & 30.

7. COMPARISON OF SIMULATED PID, GA-PID AND FLC CONTROLLER

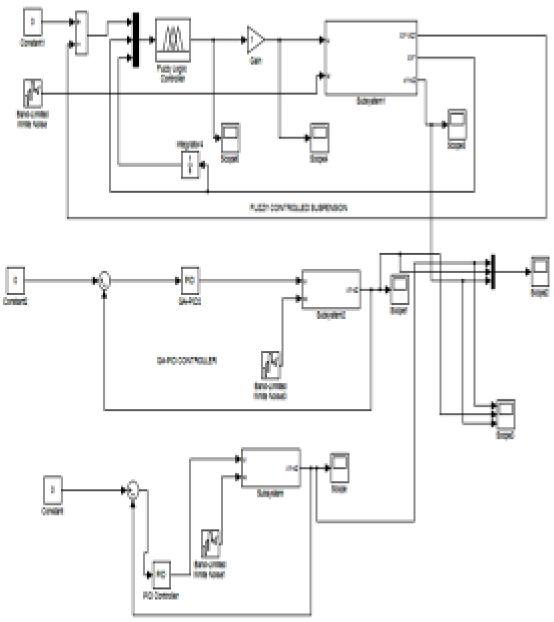


Fig. 10 Simulink model for PID, GA-PID and FLC controller

From the above simulation put the value of *Kp*, *Ki*, and *Kd* and also put new value of Gains find by GA toolbox. These three models have been operated for 5 seconds and their outputs, i.e. body deflections have been compared with each other in Figure 11. From the figure it can be seen that FLC & GA-PID controller give much better result than normal PID controller.

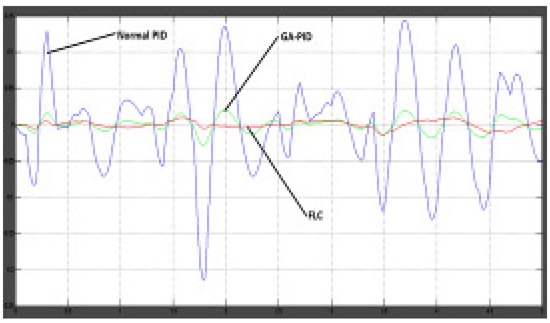


Fig.11 Comparison Result of PID, GH-PID and FLC

8. CONCLUSIONS

These models have been applied to a sample one quarter car model. The results of proposed model are compared with those of PID controller, GA-PID and FLC controller model has been assessed. It has been shown that the fuzzy-logic controller and GA-PID controller displays better performance than the PID controller for the minimization of the maximum body deflection.

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