Performance Improvement of Light Vehicle Suspension System Using PID and Fuzzy Logic Controllers

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INTRODUCTION

Current study emphasizes the investigation of suspension system performance improvement by utilizing PID and FLC approaches. Comparative performance assessments of both the controllers are carried out. The control approaches applied in vehicle’s suspension system is to maintain the magnitude of external energy source supplied for actuator dynamics. The reverse dynamic of actuator try to stabilize the body by attenuate the vibration in response to body movement and other output parameters. This actively controlled actuator injects the balancing force in the plant to minimize its unwanted movements [1].

Suspension system is directly related to the road profile; wheels come to play with road and the road inputs transmitted to vehicle body, which affects the body’s stability and comfort level of riders [2]. Here the objective is to obsolete the body from road inputs by inserting suspension system between vehicle body and wheels. Conventional suspension employed with conventional spring and dampers which store and dissipate the vibrating energy transferred from road via wheels [3]. In conventional system there is no mean by amplitude of road input or road profile, it always reacts in same manner as it is designed. Active suspension system has the ability to react in response to the road input as well as body behavior. It defines the luxuries of the vehicle.

There is a great development in this domain during last decade but apparently it was not focused on minor parametric effect such as tyre damping property, effect of vehicles body yaw and vehicles moving speed, it seems to lacking of effective parametric consideration. In the current research work, an optimized controller is suggested specially for suspension system with variant operating condition and road profile. The current plant is modeled with considering major and minor effective parameters, this makes the plant modeling typical task but the system response may achieve accurate analysis results [4].

It is fact that road may too much be plane and smooth but it behavior will never be linear, it always have some unexpected irregularities which transfers to the vehicle’s body and passengers through wheel and road contacts.

PLANT MODELING

The whole body of suspension is considered as discrete system of mass and dampers and it is modeled in mathematical form

This is an approach to find the effective and optimized controller for a light vehicle suspension system with consideration for testing on uncertain and varying road profile. The strategy is to attenuate the body vibration by reverse dynamic efforts of actuator based on controlled external source of energy. The system is shaped by implementation of PID and Fuzzy Logic Controller with primary gain setting and observed the performance of both the controllers for uncertain road trajectories. The effective parameters; for investigating the performance measure of the system; are vehicle body vertical movement, velocity and time to regain the stability. Basic PID and 25 rules based fuzzy logic controller’s efficiency is observed in various aspects, advantages and pitfalls of these control methodologies are studied. It has been observed the performance of PID controller is good for smooth road, but the uncertain road profile affects its performance while FLC achieved the better result by its variable adjustment ability.

Key Words: PID, Fuzzy Logic Controller, Suspension System, Half Vehicle, Road Uncertainty.
utilizing D-Alembert principle and energy principle approaches. The drawn equations of the plant are utilized to model on simulating platform (i.e. Simulink) for response analysis. The considered system, plant is modeled upto minor parametric effect [4]. Modeled plant is employed with PID [5] and Fuzzy logic controller [6, 7]; the plant response with both control approaches is compared for road sensing and irregularities effect on controller efficiency.

A. Mathematical Model

The four-degree-of-freedom model is adopted in this work, as shown in figure 1[5]. It is supposed that wheel contacts with road constantly in the model and the dynamic differential equations (equations-1, 2, 3 & 4) of proposed model are set up according to Newton’s second law of motion and free body diagram approach [5].

\[
\begin{align*}
\ddot{y}_s &= \frac{(y_s - y_u)k_s + (\ddot{y}_s - \ddot{y}_u)k_s + (\dot{y}_s - \dot{y}_u)k_s + (\dddot{y}_s - \dddot{y}_u)k_s}{m_s} \\
\ddot{\theta}_s &= \frac{4[(y_s - y_u)k_s + (\ddot{y}_s - \ddot{y}_u)k_s] - 2[(y_s - y_u)k_s + (\dddot{y}_s - \dddot{y}_u)k_s]}{I_s} \\
\ddot{y}_u &= \frac{(y_u - y_s)k_s + (\ddot{y}_u - \ddot{y}_s)k_s - (\dddot{y}_u - \dddot{y}_s)k_s + (\dddot{y}_u - \dddot{y}_s)k_s}{m_u} \\
\ddot{y}_t &= \frac{(y_t - y_u)k_s + (\ddot{y}_t - \ddot{y}_u)k_s - (\dddot{y}_t - \dddot{y}_u)k_s - (\dddot{y}_t - \dddot{y}_u)k_s}{m_u}
\end{align*}
\]

Identified design parameters that govern the dynamic behavior of a vehicle’s body considered for study are tabulated in table 1[5].

![Fig. 1: Four DOF suspension model](image)

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m_s)</td>
<td>Mass of vehicle’s body, kg</td>
</tr>
<tr>
<td>(l)</td>
<td>Total Length of the body, N/m</td>
</tr>
<tr>
<td>(l_1, l_2)</td>
<td>Length of the body front and rear end from centre of gravity, N/m</td>
</tr>
<tr>
<td>(k_{11}, k_{22})</td>
<td>Stiffness of the Tyre material, N/m</td>
</tr>
<tr>
<td>(k_{i1}, k_{i2})</td>
<td>Coefficient of springs, N/m</td>
</tr>
<tr>
<td>(C_{11}, C_{22})</td>
<td>Damping coefficients of the dampers, N-s/m</td>
</tr>
<tr>
<td>(C_{12}, C_{21})</td>
<td>Damping coefficients of the Tyre material, N-s/m</td>
</tr>
<tr>
<td>(I_s)</td>
<td>Moment of inertia of the body, kg m^2</td>
</tr>
<tr>
<td>(\dddot{y}_s)</td>
<td>Angular acceleration of the body, Rad/sec^2</td>
</tr>
<tr>
<td>(m_{yu}, m_{yu})</td>
<td>Unsprung masses of the suspension, kg</td>
</tr>
<tr>
<td>(y_s, y_{12})</td>
<td>Body vertical Displacements (Sprung mass), m</td>
</tr>
<tr>
<td>(y_u, y_{12})</td>
<td>Suspension Travel (unsprung mass vertical displacement), m</td>
</tr>
<tr>
<td>(y_t, y_{12})</td>
<td>Tyre vertical travel due to road disturbance (Bump Height), m</td>
</tr>
</tbody>
</table>

B. Simulink Model

During vehicle run simulation, wheel meets to any obstacle or dent, the jerk is transmitted to the vehicle body, seats and passengers, resulting vibrations must be certainly dissipated in a short period of time. As the system output, the suspension deflections, \(Y_s-Y_t\) is chosen instead of the whole system deflection, \(Y_s-Y_u\); because of the difficulties in determining of the wheel deflections. Road surface input \(tr\) taken as step input for the road profile SIMULINK model. The output, \(Y_s-Yt\) of the planned feed-back control system, is not permitted to exceed the 5% of the unit step input \(tr\) and the dissipation of the vibrations is required to occur in a time shorter than 5 seconds.

The development of controllers in simulation by MATLAB program is used to view the suspension system performance by simulation responses. This allows user to see the comparison between the active and passive response plot for both control methodologies in varying work environment. The developed SIMULINK basically, consists of two main subsystems with the road disturbance being injected to simulate the actual vehicle performance. The controllers need to be carefully tuned to get the best response. The time response plot is obtained during simulation while considering passive and active system is shown in Figure 2.

![Fig. 2: Block diagram of the model of active suspension system with PID and FLC](image)
SIMULATION RESPONCES

The responses are recorded for 100 seconds in varying road profile (i.e. Jerk intensity and number of bumps hitting by the vehicle). Analysis is done for open loop system without controller (passive system), system with PID controller and Fuzzy logic Controller for linear model. A comparative assessment of the impact of the PID and FLC models on the system performance is presented and discussed.

A. Displacement-time response for single jerk step input

As the simulation starts vehicle experienced a jerk is due to front wheel hits on bump of a 0.1 m height. After 0.84 seconds, vehicle again experienced same jerk for rear wheel. The response recorded of vehicle with 0.1m step input for passive & PID and passive and Fuzzy Logic controlled system as shown in Figures 3 and 4 respectively.

![Fig. 3: Passive and PID controlled system comparative response plot of vertical body deflection](image)

![Fig. 4: Passive and Fuzzy Logic controlled system comparative response plot of vertical body deflection](image)

B. Displacement-time response for multiple jerk step input

Here analyzing the model for multiple jerks of different intensities injected to the vehicle, Suspension hits back to back on two continuous road bumps of 0.3 m and 0.1 m heights with transport delay of 15 seconds. Figures 5 and 6 shows the comparative response plots on single scale for active and passive system.

![Fig. 5: Passive and PID controlled system comparative response plot of vertical body deflection](image)

![Fig. 6: Passive and Fuzzy Logic controlled system comparative response plot of vertical body deflection](image)

C. Velocity response for single jerk step input

It is apparent from the Figures 7 and 8, when the responses are plotted on same scale, body vertical velocity get reduces up to ground value within 5 sec, its means vehicle gets stable condition in a short time and reduction in threshold value of velocity is also considerable.

![Fig. 7: Passive and PID controlled system comparative response plot of vertical body velocity](image)
D. Velocity response for multiple jerks step input

It can be observed from the plotted responses, when the vehicle hits on first bump of 0.3 m height, it is considered the initial point of vehicle from where it starts running and at that point running velocity will be slightly increase from zero. So effect of this jerk is not so much as next bump because vehicle hits on next bump after 15 seconds transport delay and at this time it attains the speed, so the effect of second bump (0.1 m) is more on vehicle. The plots show the responses for these iterations, Figures 9 and 10 shows the comparative analysis on single scale for better understanding.

SIMULATION RESPONSES

The common parameters for the comparison are overshoot OS, settling time TS, and steady state error SSE, of the linear model using two control approaches. The simulated model is analyzed after running it to predefined time of 100 seconds for several kinds of operating conditions and different observations are drawn in light of the performance and behavior of suspension system. The results are obtained for step type of road surface inputs and following conclusions are drawn:

- A 25-rule Fuzzy controller have given fine results but not good as PID, however, increasing rule numbers are not preferable since the number of the rules affect the processing time of the Fuzzy algorithm.
- It is obvious; if the numbers of Fuzzy rules will increase it can provide the better results than PID.
- It could possible PID can gives the better results than FLC for the particular designed conditions but if operating parametric uncertainty is there then efficiency of PID tremendously get reduce and apart from this FLC have the ability to changes its design variables in response to the input values to meet the desired response.
- This is the superiority of the FLC model to the PID controlled model. Because PID has the drawbacks that it cannot change its designed gain values in response to input parameters.

REFERENCES