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Deep Learning based Nonlinear Active Suspension Control

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Abstract--- *Design of comfortable and effective active-suspension system of the vehicle has been enthralling and tough control-engineering workbench-problem. Passive and active suspension system model has been outlined as Quarter model (1/4th wheels) with spring-damper arrangement. The proposed model is for a execution of active-suspension system with actuator (final control element) is incorporated that can create the control output, 'Uc (t)' to control the movement of the vehicle. This paper proposes Deep learning based Modified PSO (DMPSO) for effective nonlinear active suspension system. In the General PSO, the development of a molecule is represented by three practices to be specific latency, intellectual and social. The subjective conduct helps the molecule to recall its past went to best position. This proposed PSO splits the psychological conduct into two segments like previous (past) went by finest (best) position and furthermore past went to most perceptibly appalling position. This change causes the molecule to look through the objective exceptionally successfully. DMPSO approach is proposed to increasing ride comfort results in slighter damping and superior suspension strokes in the vehicle.*

KEYWORDS: Dynamic system; Suspension; modeling; PID; Optimization; DMPSO;

I. INTRODUCTION

In conventional suspension designs, the passive elements consist of damper and spring combination and the modern active suspension system provides additional energy to the mechanical linkages. while disturbance occur because of variation in road profile. Spring element consumes power from mass of vehicle body and dampers release that power of spring by means of designing adequate controller. The advanced controller provides better stability [1] for the vehicle while in the case of deterministic and stochastic disturbance environment. In chapter II, the detailed explanation about system modeling is discussed. Chapter III deals with proposed DMPSO algorithm and its designing stages. DMPSO based controller design has been implemented to provide better control effort [2] for active-suspension system. Chapter IV discusses the various results of proposed controller and it is compared with conventional control techniques. The simulation results are the evident of proposed control strategy provides the optimum control effort, so that the passengers inside the vehicle feels sophisticated environment while the vehicle undergone measured or unmeasured disturbance conditions.

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II. SYSTEM MODELING

Fig.1. Schematic view of 1/4 car model

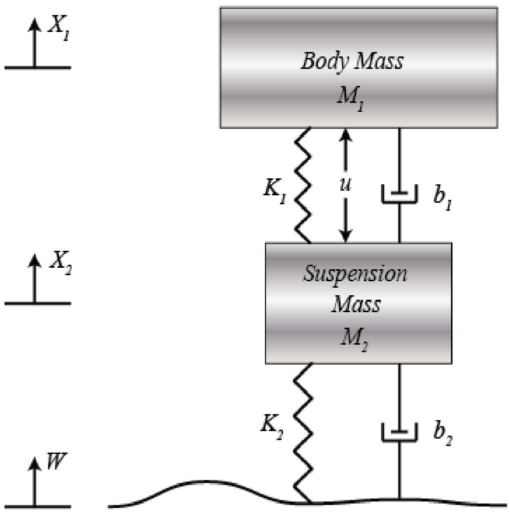

Fig.2.Free body diagram of 1/4 car model

Figure 1 and 2 shows the schematic and free body diagram of quarter (1/4) car model. By applying first principle method the system transfer function model has been obtained based on input, output and disturbance parameters. Table 1 shows the system parameters with its quantified values.

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Table 1.1 Proposed System parameters

Symbol	Parameters	Value
[M_1]	1/4th car body-mass	1500(kg)
[M_2]	Suspension-mass	220(kg)
[K_1]	Suspension-system-spring constant	50,000(N/m)
[K_2]	Wheel & tire-spring constant	300,000(N/m)
[b_1]	suspension system-damping-constant	250 (N.s/m)
[b_2]	damping constant of wheel & tire	15,020 (N.s/m)
[U_c]	Output of controller force	$U_c(t)$

Based on Newton's Law, the motion equation as,

$$M_1\ddot{X}_1 = -b_1(\dot{X}_1 - \dot{X}_2) - K_1(X_1 - X_2) + U \ (1)$$

$$M_2\ddot{X}_2 = b_1(\dot{X}_1 - \dot{X}_2) + K_1(X_1 - X_2) + b_2(\dot{W} - \dot{X}_2) + K_2(W - X_2) - U \ (2)$$

From figure 1 and 2, the transfer function model has been derived and it is accept that the initial conditions are assumed to be zero, with the goal that these conditions converse to the condition that the vehicle tires moves up a blow. By taking the Laplace Transform the dynamic system has been converted to S-domain specifications. [3], [4]. The transfer function G1(s) and G2(s) is gives the information about dynamic changes in active suspension system. The variable U and W are control effort and disturbance signal respectively.

When consider the control input, U(s) and the road disturbance, W(s) = 0. Thus the transfer function G1(s) has been arrived.

$$G_1(s) = \frac{X_1(s) - X_2(s)}{U(s)} = \frac{(M_1 + M_2)S^2 + b_2 s + k_2}{\Delta} \ (3)$$

If only the disturbance input W(s) considered, then the control input $U_c(s) = 0$. Thus the transfer function G2 (s) has been arrived.

$$G_2(s) = \frac{X_1(s) - X_2(s)}{W(s)} = \frac{-M_1 b_2 s^3 - M_1 K_2 s^2}{\Delta} \ (4)$$

Where,

$$\Delta = (M_1 S^2 + b_1 s + k_1) \cdot \left(M_2 s^2 + (b_1 + b_2)s + (k_1 + k_2)\right) - (b_1 s + k_1) \cdot (b_1 s + k_1) \ (5)$$

The equation 3 gives the transfer function model of car with control input and equation 4 gives the transfer function model with disturbance input.

III. DEEP LEARNING BASED MODIFIED PSO (DMPSO) ALGORITHM FOR CONTROLLER DESIGN

DMPSO method depends on iterative and evolutionary soft computing approach based optimization technique. In the initial stage the present system model state has been examined and a cost minimization control methodology (function of minimum search) is figured (through a numerical minimization calculation). The computation has been used to explore the status directions that exude from the present state and then calculate (based on Euler & Lagrange conditions) a minimization of cost function based control technique [5], [6] has been implemented, in that instant the system state is verified another time and the counts are continued up to the new and recent state arrived. This implies another control and new predictable state. The prediction of future state continues being moved forward and hence DMPSO is additionally called retreating state vector control. DMPSO gives better control effort for both stochastic and deterministic disturbances affect the system parameters. This algorithm provides optimum settings for controller parameters in-order to obtain optimum control voltage to the final control element (actuator).

The n^{th} order Linear-Time Invariant -Continuous system has been represented by equation (6),

$$G(s) = \frac{N(s)}{D(s)} = \frac{\sum_{i=0}^{n-1} A_i s^i}{\sum_{i=0}^{n} a_i s^i} \ (6)$$

In equation 6, D(s) & N(s) are denominator and numerator polynomial respectively. A_i & a_i are the constant coefficients of the 'S'-terms of the numerator and denominator of transfer unction gain variable *G (s)*.

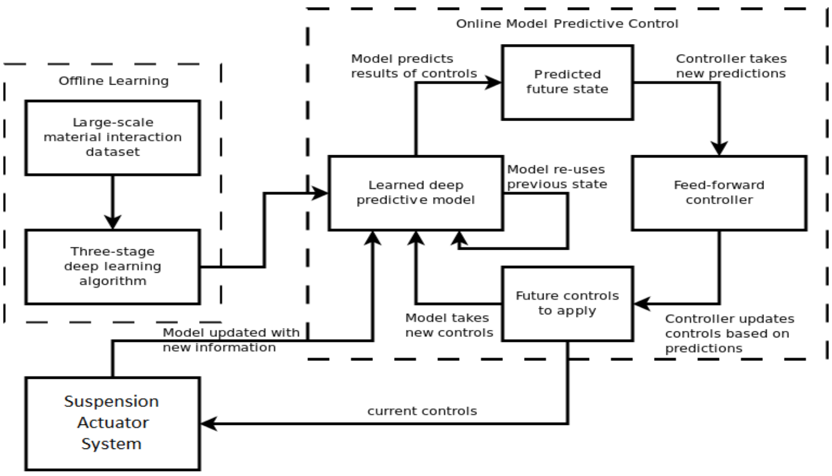

Fig.3. Deep learning based control algorithm for Suspension control Process

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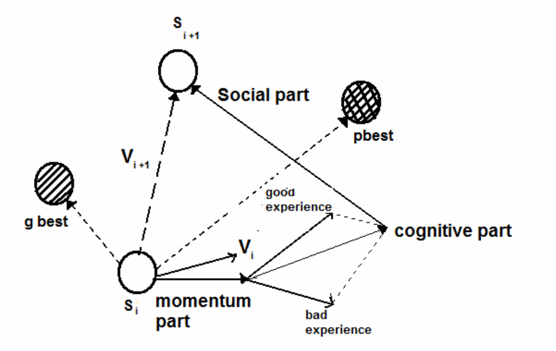

Fig.4. Concept of DMPSO search point

DMPSO-Position information (updates) are given in equation (7) as,

$$S_{i+1} = S_i + V_i + 1 \quad (7)$$

Based on mathematical equation (6, 7) all the individual particles are trying to modify (change) its speed or velocity & location or position for reaching its target. The speed or velocity of particle is denoted as $'V_i'$, the present (current) location or position of particle is denoted as $'S_i'$, Inertia weight as 'ω', coefficient of cognition acceleration as 'C1', coefficient of social acceleration as 'C2', = The optimum best position of particle as *'Pbesti'*, = The best optimum Global position as '*gbesti'* among the group of particle. The random numbers r1 and r2 are uniformly distributed [7], [8] within the range of [0 to 1].

A. Design Procedure:

Stage I: choose the quantity of individual-particles, ages, tuning-coefficients C1g, C1b, C2 and irregular numbers r1, r2, r3 to begin or start the initial process

Stage II: initialize the particles location or position and speed or velocity.

Stage III: choose the particles, singular-optimum best an incentive for every age.

Stage IV: choose the particles globally as best-optimum esteem, i.e. molecule close to the objective function amongst every one of the particles is gathered by distinct all the individual best optimum qualities.

Stage V: choose the particles singular, most perceptibly dreadful (bad) esteem, i.e. Molecule too far from the objective function.

Stage VI: modify or update the particles, singular best (pbest), globally-best optimum (gbest), molecule most noticeably awful (Pworst) in the speed condition and acquire the new velocity or speed.

Stage VII: modify or update recent (new) velocity or speeds and incentive in the condition and acquire the situation of the particles.

Stage VIII: Identify the final-end combinations with least Integral Square Error (ISE) by the re-energized new speed or velocity and location or position.

B. Time domain and Frequency domain Analysis:

With the help of MATLAB the open loop (without any feedback) performance of the suspension system has been analyzed for given step change (actual force U(s) input) and it is given in the Fig.5.which indicates under-damped behavior [9], [10]. Passengers sitting inside the car will feel very minor oscillation but moreover the settling time is very high to attain steady state position.

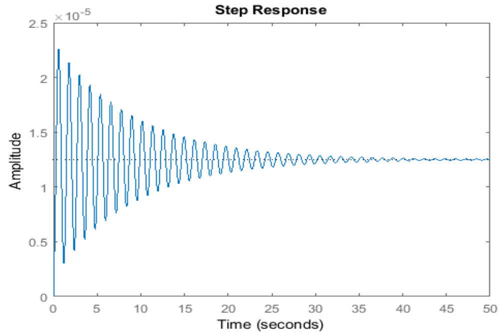

Fig.5. Open-Loop graph (Unit-Step response) of Active-Suspension system for actual force input

Now just consider about disturbance affecting the suspension system as W(s) with the magnitude of 0.2m

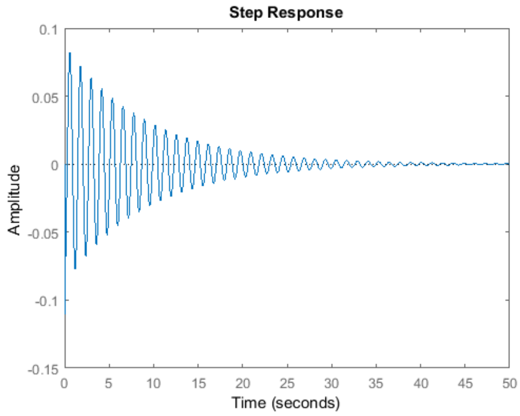

Fig.6. Open-loop graph (Unit-Step response) of Active-suspension system for disturbance W(s)

From the Fig.6. Due to larger peak overshoot and higher settling time Passengers sitting inside the car may feels uncomforted. So that the solution for this suspension problem [11], [12] is to design effective feedback control based on Deep learning based Modified PSO algorithm (DMPSO).

First the conventional PID controller has been designed and then it has been enhanced by DMPSO algorithm.

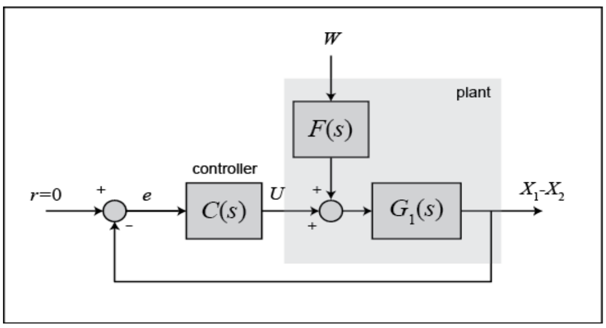

Fig.7. DMPSO based closed loop PID controller Design for suspension system

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Fig.7 shows the DMPSO based closed loop control of suspension system and the transfer function model for PID controller [13], [14] is given in equation (8) and initially the K_p, K_i and K_d values are tuned under trial and error method after that tuning mechanism carried out by Ziegler and Nichols and Cohen and Coon method.

$$C(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s} \quad (8)$$

Where,
K_p=208025, K_i=832100 and K_d=624075

IV. RESULTS AND DISCUSSIONS

Figure 8 shows the closed loop response of active suspension system. It is observed that the peak overshoot is 9mm which is more than that of desired 5mm but the settling time is below 5sec. In order to rectify that bode diagram based frequency synthesis method is used to identify phase margin and gain margin of the suspension system.

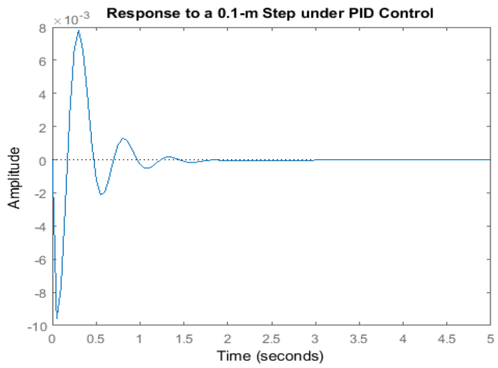

Fig.8.Closed loop PID controller response of Active-suspension System

The DMPSO based closed loop controller [15] has been designed to control the active-suspension system beneath various-road disturbances (W), that is simulated using unity step change signal and the X1-X2 is the output which should have the less than 6 seconds-settling-time and an less than 6% of peak-overshoot. For an instance, when the vehicle moves on the road onto a 10-cm step, the vehicle body will oscillates within a range of +/- 6 mm and will stop oscillating within 6 seconds.

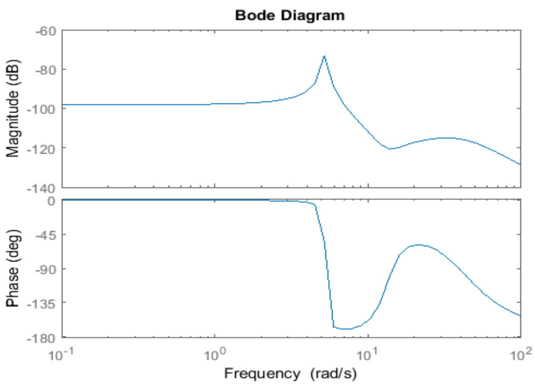

Fig.9. Bode plot for calculating Phase and gain of the suspension system

By commencing the Fig.9 it is observed that the curved in segment of the phase plot is greater than -180 degrees and the phase margin is adequate for the objective function. The DMPSO algorithm provides satisfactory response for the suspension system, shown in Fig.10.

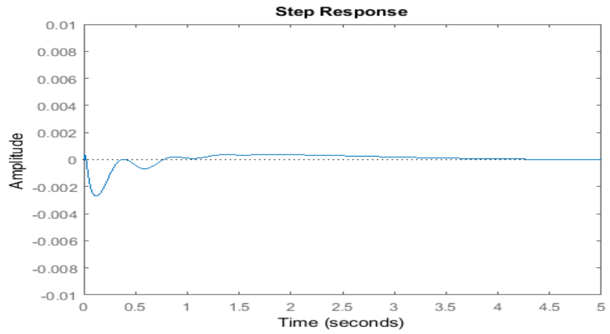

Fig.10.Closed loop DMPSO algorithm based controller Response of Suspension System

By commencing the Fig.10, It is experiential that the percent overshoot is concerning 0.155 mm a lesser amount of the previous plot and the settling time also fewer than 6 seconds. This response is now acceptable and no more further design iteration is required.

V. CONCLUSION

By commencing figure 5 and 6, it is clearly observed that the need of closed loop control for effective suspension system for passenger inside the car during travel. From Fig 8 It is clearly observed that the conventional PID controller does not provide satisfactory control action and then from the Fig 10 it is observed that the proposed DMPSO algorithm based controller design provides satisfactory control output and ensures the well comfort zone for passengers inside the car while both disturbance and breaking elements encountered in the system dynamics.

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