Predictive Semi-Active Suspension using Genetic Algorithm

Johann Koshy
Mechanical Engineering
University of Cincinnati
Ohio, USA

Shashank S Iyengar
Mechanical Engineering
University of Cincinnati
Ohio, USA

***Abstract*— A conventional suspension is able to reduce the road loads only to a certain extent due to limitations in mechanical and material properties. Employing a variable damping system can alter the ride comfort depending on the terrain. Ride & handling is one of the key selling points of an automobile. In this study, the effectiveness of variable damping was analyzed using Genetic Algorithm to optimize and obtain near optimal solutions for continuously changing road profiles.**

Keywords—Semi-Active, Suspension, Genetic Algorithm, Variable, Damping, Quarter-Car Model

I. INTRODUCTION

1.1 Suspension

Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two [1]. Suspension systems must support both roadholding/handling and ride quality [2]. which are at odds with each other. The tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension of a car may be different.

The limit on passive suspension system performance has resulted in growing interest in semi-active and active suspensions. In active suspensions, an actuator is added to each suspension [3]. An active suspension system possesses the ability to reduce acceleration of sprung mass continuously as well as to minimize suspension deflection, which results in improvement of tire grip with the road surface, thus, brake, traction control and vehicle maneuverability can be considerably improved [4]. A lower cost, intermediate solution is to use a semi-active suspension. Most of the applications of semi-active suspensions use an adjustable damper [3].

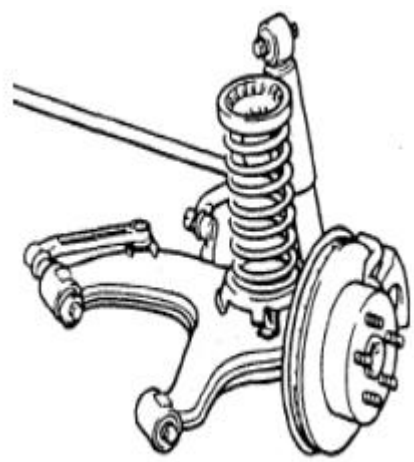

Fig. 1 Suspension Components [4]

With the help of control system, various semi-active/active suspensions realize an improved design compromise among different vibrations modes of the vehicle, namely bounce, roll, pitch and warp modes. Commonly used control strategies for semi-active suspensions:

Reactive Methods:

- Skyhook Algorithm
- Groundhook Algorithm
- Hybrid Control
- Linear Quadratic Gaussian Control
- Non-linear control

Predictive Methods:

- Fuzzy Logic
- Genetic Algorithm

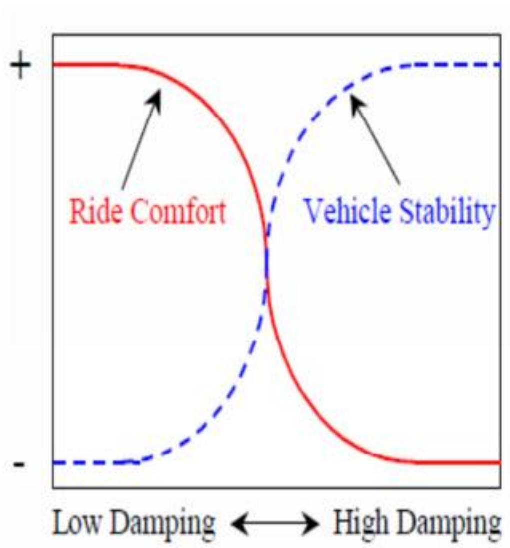

Fig. 2 Comfort-Stability vs Damping [4]

1.2 Genetic Algorithm

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution [2].

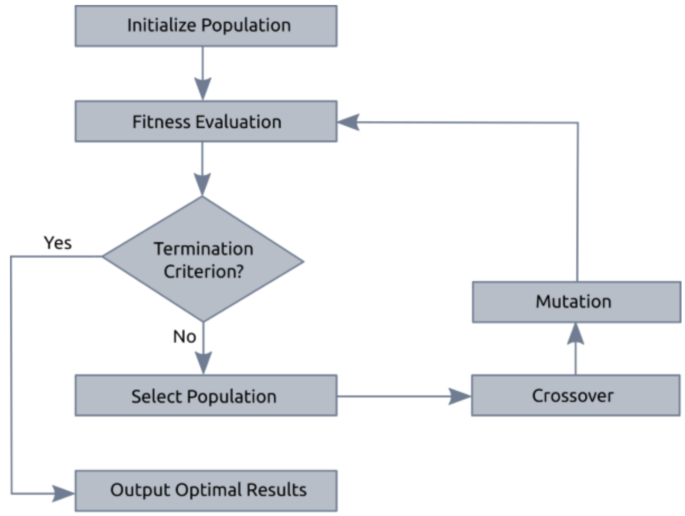

Fig. 3 Genetic Algorithm Flow

II. Mathematical Model

2.1 Quarter Car Model

The quarter car model is the most commonly used design model to perform analysis on a suspension system. It is represented by the following figure:

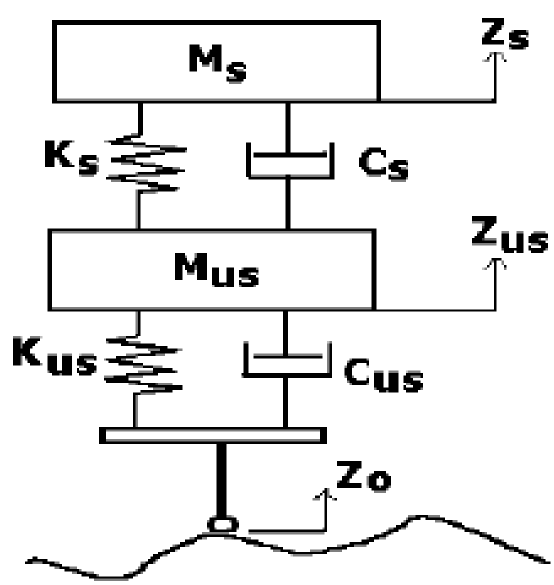

Fig. 4 Schematic Quarter Car Model [4]

This represents a two-degree of freedom system where M_s is the sprung mass and M_{us} is the unsprung mass. The corresponding *K's* and *C's* represent stiffness and damping for the two masses respectively.

2.2 Equations of Motion

For a single degree-of-freedom (SDOF) system, the force balance equation is given by:

$$m\ddot{x} + c\dot{x} + kx = f(t)$$

where,

$c\dot{x}$ is the damping force

kx is the spring force

$f(t)$ is the forcing function

In addition to this, the suspension model is synonymous to that of base excitation. It is represented by the following figure:

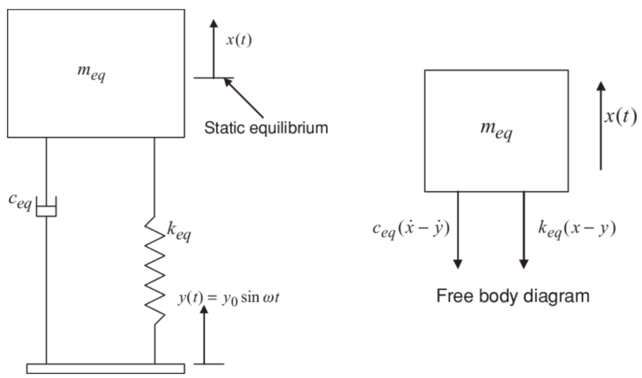

Fig.5 Base Excitation of SDOF system

From Fig.4, the force balance equation for base excitation is given by:

$$m\ddot{x} + c(\dot{x} - \dot{y}) + k(x - y) = f(t)$$

For a two-degree of freedom system:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F\}$$

III. WORKFLOW

- Road data available from Lidar and Camera mounted on the vehicle
- The data is fused and a predicted road profile is generated
- Optimize damping response for predicted road profile using GA
- Population contains a combination of set number of damping coefficients
- Acceleration and displacement response is calculated for each chromosome and fitness is assigned
- GA computes near optimal damping ratio

IV. PSEUDO-CODE

Start Program

Chromosome: Randomly create cities damping coefficients in the range 105-130 lb-s/ft

Construct Initial Population

For

Randomly select parents for crossover

Produce children from said crossover

At random intervals, introduce few entirely new parents into population pool (Gene Flow)

Mutate children with probability increasing to better represent diversity

Add children to population

Compute fitness and reduce population

End

Track global minimum average sum of displacements and accelerations

Plot results of optimal solution found from GA

End Program

V. CONSTRAINT HANDLING

- Let x be the vertical displacement of the suspension setup and $\ddot{x}$ be the acceleration response at the same time step.

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- Ride comfortability is improved if both x and $\ddot{x}$ are as low as possible.
- Individually minimizing x and $\ddot{x}$ does not guarantee reduction in vibration due to the competing nature of displacement and acceleration as seen in Figure 2.
- Therefore, fitness is evaluated based upon the following criteria:

$$\min(K|x| + |\ddot{x}|)$$

- Secondary constraint handling condition:

$$|\ddot{x}| < 4.9\, m/s^2$$

i.e., acceleration should not exceed 0.5g

- Suspension working space - absolute relative displacement between sprung and unsprung masses:

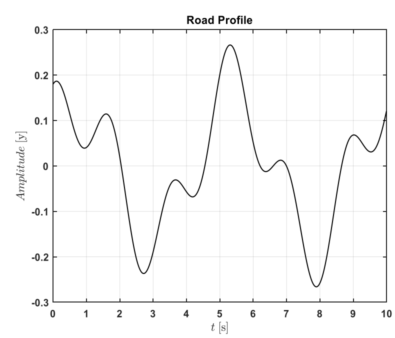
$$|x - y| = 0.1524m$$

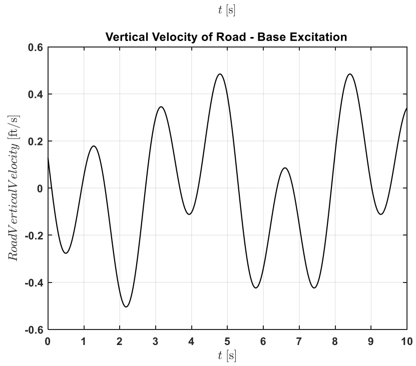
VI. ANALYSIS

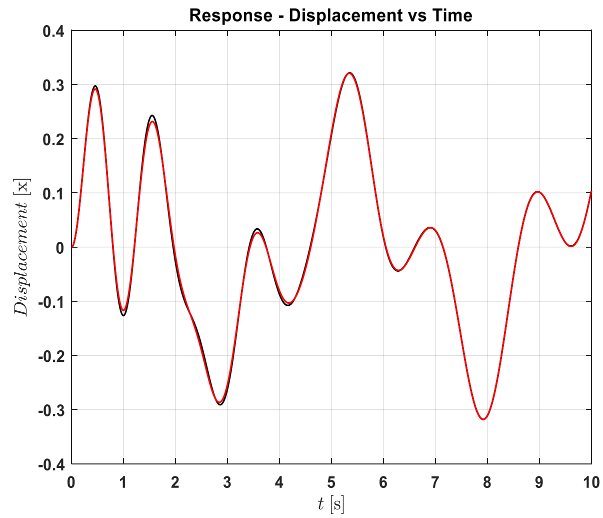
Case 1:

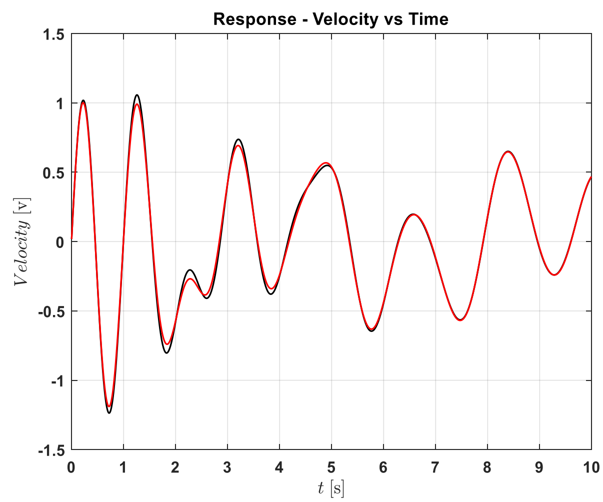
Specs:

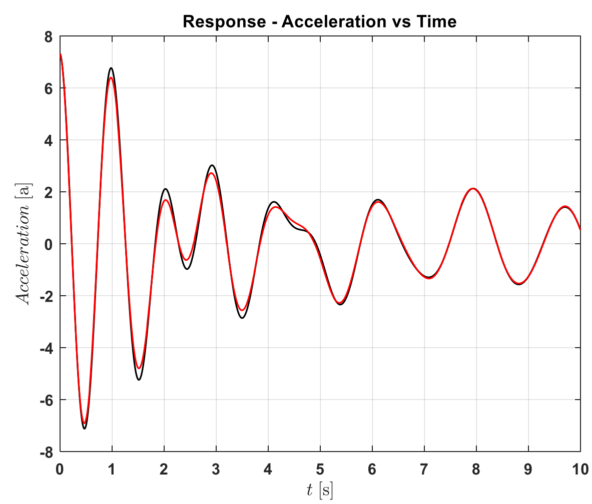
- Chromosome length – 2000
- Number of generations – 5000
- Damping Ratio range (C) – 100 to 120

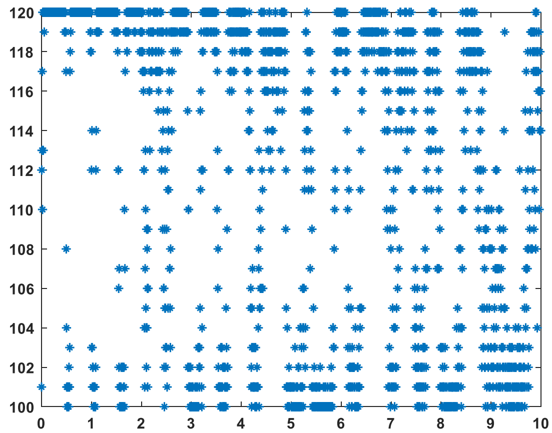


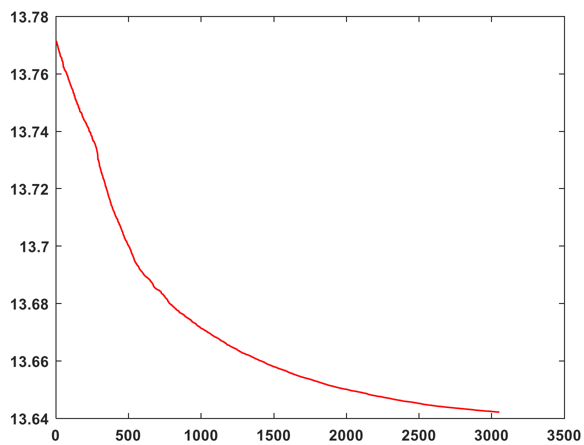












Case 2:

Specs:

- Chromosome length – 200
- Number of generations – 5000
- Damping Ratio range (C) – 100 to 120
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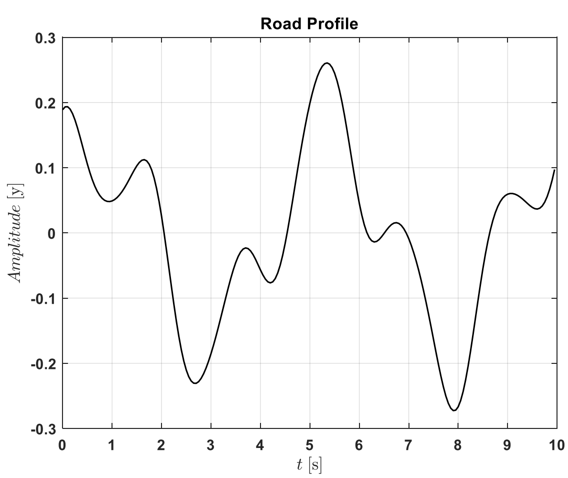

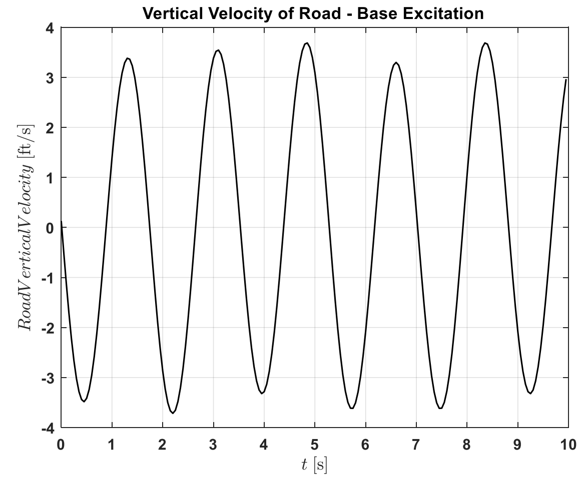

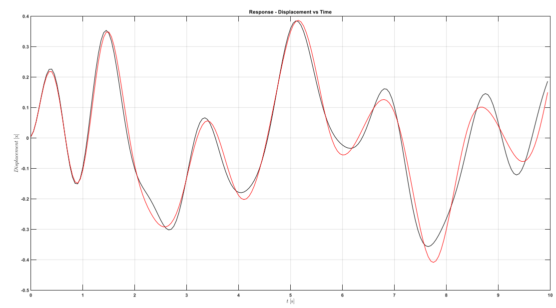

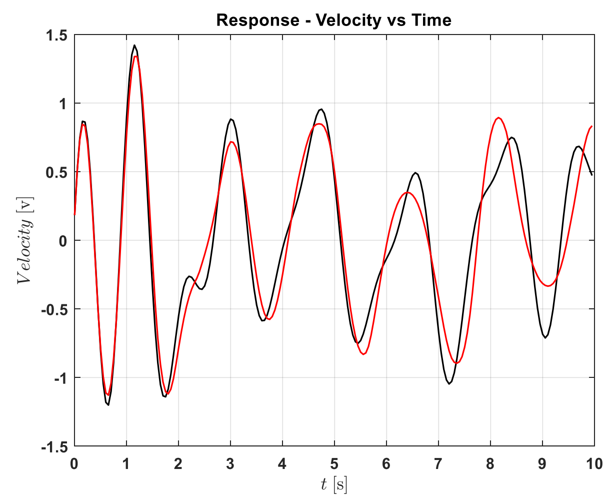

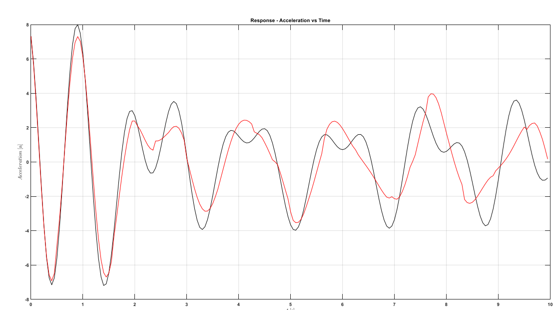

VII. CONCLUSION

Genetic algorithm optimization is a global optimization technique, searching for a design that minimizes an objective function subject to constraints. In all simulation runs, it can be observed that the genetic algorithms have been able to find optimal damping ratios for the given suspension setup. To further improve efficiency and consistency in the results, the GA parameters, such as population size and mutation probability, may be tuned more effectively.

Furthermore, this optimization model can be extended in incorporate the pitching and roll body dynamics of the car which would expand the optimization parameter ranges.

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