Optimization of Automobile Suspension System Using Hybrid GSA Algorithm

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Abstract. In this paper Hybrid Genetic-Simulated Annealing Algorithm (GSA) is studied and applied to the suspension system of an automobile with two different case studies. Mathematical modelling of an automobile is done for passive suspension system. GA, SA and GSA were simulated using programming in MATLAB. First case study is based on the data of researcher in the field where GA was applied for optimization of automobile suspension system. Here SA, as well as Hybrid GSA are applied and compared with the results of GA. Convergences of the three methods are also plotted. In second case study an automobile model MARUTI 800 is considered. All the necessary parameters are calculated through measurements. The results shows required seat acceleration for current available springs of the automobile in field. For both the case studies the Hybrid GSA shows best results among the three. This can be performed before actual manufacturing of springs and automobile to check whether desired seat acceleration and ride comfort will achieve or not. If it is satisfied with the value of seat acceleration, decision would be made regarding manufacturing of springs with those values of stiffness and damping constants.

1. Introduction

The Suspension system of an automobile is often a most important part of it, due to its safety features, shock absorption and stability during running conditions. It is basically the combination of springs, shock absorbers and mechanism that connects the body of the Automobile to the chassis. The suspension system can be active or passive. Active suspension system has components which needs power for their working operation unlike passive suspension. Now a days a semi-active suspension system have been used which is combination of active and passive suspension system.

Genetic algorithm (GA) is the optimization technique which imitate the process of natural genetics [1,2]. GA initially considers the population of each parameter from its history and selects two parameters for its processing which includes mutation, crossover where the feasibility of the parameters is checked for their survival in the field of application.

Some researchers [2] have explain the Genetic algorithm optimization and applied it to the suspension system of an automobile in view of optimum seat acceleration. Mathematical modelling were done based on equivalent system of an automobile. The parameters were optimized for their best utilization. Few investigators have used GA for solving the poor linkage version of the problem where the order of genes is randomized, and crossover is unable to extract and recombine good building block [3]. The GA can be applied to various system by changing the pattern of genes.
Simulated annealing (SA) is the optimization algorithm which is based on the way a metal get heat treatment by the process of annealing through heating at certain temperature and slowly cool down in environment to relieve the internal stresses [4]. With the reference to previous experience of the material highest possible set point is decided and named as initial temperature and then neighbourhood point will be checked more precise and optimum value of an output.

Optimization using GA works on the globalization of the parameters whereas it is using SA by localization of the parameters, this inspires to combine the two concepts to get the more effective solution. Several attempts have been made to hybridize the GA and SA and proven to be good. Balram Suman had used four different Simulated Annealing algorithm to solve multiobjective optimization problem [4]. Sanjay Bisht gives a conceptual basis for Hybrid Genetic and simulated annealing optimization applied in the field of Defense [5]. Younis Elhaddad et al. had applied the Hybrid Genetic and Simulated Algorithm to Traveling salesman problem [6]. A.H. Gandomi et al. gives a concept of Hybrid Optimization applied to study the Behavior of Bolted joint [7]. M.J. Thoresson et al. had proposed a methodology for the efficient determination of gradient information, when performing gradient based optimization of an off-road vehicle’s suspension system [10]. M. Yogeswarana et al. discussed a machine loading problem in a flexible manufacturing system (FMS), with bi-criterion objectives of minimizing system imbalance and maximizing system throughput in the occurrence of technological constraints such as available machining time and tool slots [11]. M. Lozano et al. had explain that the flexible architecture of evolutionary algorithms allows specialized models to be obtained with the aim of performing as other search methods do, but more satisfactorily [12].

Suspension system of an automobile is the combination of different springs and their location with respect to mass center of an automobile, vibration absorbing dampers. The important Parameters used to design an automobile suspension system are:

1. Springs stiffness.
2. Deflection of the springs.
3. Placement of spring relative to C.G of the automobile.
4. Vibration reducing units such as Dampers.
5. Amplitude of vibration of tires due to contact with road surface.

These design variables have linked with ride comfort. It is tried here that these Design parameters shall be selected for minimum seat acceleration i.e. maximum ride comfort.

In this paper an equivalent mathematical model of an automobile is considered with specified design parameters. Considering the variation in the values of the parameters and other dimensions of the automobile a Programming is done in MATLAB for GA, SA and GSA for two case studies separately. To validate the results a similar automobile model is developed in MSC.ADAMS (a dynamic analysis software package) with the obtain values of spring stiffness and damping constants from programming.

2. Mathematical Modelling

The equivalent model of an automobile is developed considering the automobile suspension system with 5 degrees of freedom which represents the independent generalized co-ordinates with following co-ordinates \( q = [q_1, q_2, q_3, q_4, q_5, q_A, q_B] \)

The suspension of an automobile is controlled by the force vibration equation:

\[
[M]\dddot{q}+[C]\dot{q}+[K]q=f(t)
\]  

Where, \( \dddot{q} \) is the Acceleration of seat which decides the ride comfort of an automobile, \( \dot{q} \) Deflection of the springs with time, \( q \) Deflection of springs.

This equation is being apply for each Wheel in terms of all parameters and rearrange it to get \( \dddot{q} \).

Ride comfort is chosen to be the criteria for optimization of suspension system, which depends on the amplitude of Seat acceleration and is expressed as,

\[
\min[f(x)] = \min|\dddot{q}|
\]
Assuming that all dampers and springs behave linearly, $\ddot{q}$ Seat acceleration, is to be optimized by selecting other parameters in that equation.

Elaboration of the same can be shown as,

$$\ddot{q} = \frac{F-(C_1 \times \dot{q}_1-(K_1 \times q_1))}{M} + \frac{F-(C_2 \times \dot{q}_2-(K_2 \times q_2))}{M} + \frac{F-(C_3 \times \dot{q}_3-(K_3 \times q_3))}{M}$$

Where,

- $F$= Spring Force which depends on the total mass of the Automobile in Newton.
- $M$= Total mass of automobile in kg,
- $K_1, K_2, K_3$= Stiffness of springs of Seat, Rear and front in N/m respectively,
- $C_1, C_2, C_3$= Dampers at Seat, Rear and front in N.s/m respectively,
- $K_1, K_2, K_3, C_1, C_2, C_3$ = Design Variables,
- $q_1, q_2, q_3$ = Respective deflections at Seat, Rear and front suspension in meter.
- $\dot{q}_1, \dot{q}_2, \dot{q}_3$ = Change of respective deflection per unit time in m/s.

Now it is required that $\ddot{q}_1, \ddot{q}_2, \ddot{q}_3$ should be related with the design parameters, for this purpose the basic concept of Stiffness is used. From the concept, stiffness is given by the spring force per unit of deflection. If stiffness and spring force is known it can be written as,

$$\text{Deflection, } q = \frac{\text{Spring force}(F)}{\text{Stiffness}(k)}$$

This equation is used to calculate $q_1, q_2, q_3$ at respective Design variable.

Figure 1: An equivalent Mathematical Model of an automobile.

With dimensions $a=2.03m$, $b=0.25m$ and $d=0.76m$ and Vehicle velocity $V=25$ m/s.

Maximum value of seat acceleration cannot exceed the acceleration due to gravity, since it violate the principles of gravity.

Constraint 1: $g_1 = f - 10 \text{ m/s}^2 \leq 0$

Following are some constraints that are placed on the system so that its movement will be restricted, so that the tire deflections and relative spaces between bodies are restricted by,

Constraint 2: $g_2 = |q_4(t) - q_6(t)| \leq 0.050m$

Constraint 3: $g_3 = |q_3(t) - q_2(t)| \leq 0.050m$

Constraint 4: $g_4 = |q_1(t) - q_3(t)| + b q_5(t) \leq 0.050m$

Constraint 5: $g_5 = |q_2(t) - q_1(t) + a q_4(t)| \leq 0.12m$

Constraint 6: $g_6 = |q_4(t) - q_4(t) - (b+d) q_5(t) - q_4(t)| \leq 0.12m$.

0.050 meter and 0.12 meter are the restrictions placed on the difference of respective deflections of the automobile considered whose values may be change when automobile model is different.
\( \dot{q} \) is defined as an objective function and 
\( K_1, C_1, K_2, C_2, K_3, C_3 \) are the design variables

1. Generate an initial population for each design variable.
2. In the population, design variables are decoded as 0 or 1 and are called as a chromosome.
3. Find the objective function \( \dot{q} \) for each chromosome.
4. For selecting two design variables for mating, SA approach is used.
5. In Mutation all selected mates have to show their survival.
6. Crossover
7. Checking for fitness of each design variable.
8. Is the criteria satisfied?
9. Store the best solution.

End

Figure 2: Hybrid GSA Algorithm
3. Hybrid GSA algorithms applied to the automobile suspension systems

3.1 Case Study I

In this case study data used by A.E. Baumal [2] et al. is considered. Dimensions of automobile Upper bound and lower bound on design variables, probability of mutation, probability of crossover, mass of automobile and it's mass moment of inertia etc. all the values are used by them. As this analysis requires large computation work that could not be done manually, which is done here using a MATLAB program. The researchers did optimization of suspension system by Genetic Algorithm. Here it is done by Genetic Algorithm, Simulated Annealing Algorithm and Hybrid Genetic and Simulated Annealing Algorithm (GSA). Results have been validated by literature as well as MSC.ADAMS.

3.2 Case Study II

An automobile MARUTI 800 is consider for the application of the hybrid optimization technique. Mathematical model is considered for this case also and the parameters like location of springs on the Chassis, values of Stiffness of springs and damping constants of dampers were determined. The values of stiffness of the springs are measured as:

\[ K_1 = 800 \text{ N/m}, \ K_2 = 20000 \text{ N/m} \text{ and } K_3 = 16670 \text{ N/m} \text{ (for half model of automobile)}. \]

As MARUTI 800 has independent suspension system, a damper is placed with every coil spring. The value of damping constant for the damper is depend on it’s size. Taking help of expert the values of damping constants of the dampers as per their size for MARUTI 800 are: \( C_1 = 100 \text{ N.s/m}, \ C_2 = 350 \text{ N.s/m}, \ C_3 = 850 \text{ N.s/m}. \) Other dimensions of automobile are:

1. Distance of back wheel from Centre of Gravity. Considering C.G. in between centre of automobile and engine mounted on the chassis, towards the engine (a) is 1.7 m.
2. Distance of driver seat from C.G. (b) is 0.295m.
3. Distance of front wheel from C.G (d) is 0.18m.

4. Results and discussions

4.1 Case study I

Case study 1 is based on the data from literature, therefore results obtain through current model should come close to the literature, so as to validate them.

Also to validate the results an equivalent model of an automobile is developed in dynamic analysis software package MSC.ADAMS. Results obtain from the dynamic analysis are compared with those obtain through analytical method in MATLAB.

The number of population is taken as 500 and number of generation is taken as 500. These number of population and number of generation can be varied for different Run. Thousands of values for both number of population (NP) and number of generation (NG) can be used.

Minimum Seat acceleration \( (\ddot{q}) \) is obtain from Hybrid GSA algorithms, which can be seen from table 1. It is also said that, to get optimum ride comfort i.e. Minimum seat acceleration, springs with stiffness \( K_1, \ K_2 \) and \( K_3 \) and dampers with damping constant \( C_1, \ C_2 \) and \( C_3 \) should be selected. Changes can be made in the number of population (NP), number of generation (NG), probability of mutation and probability of crossover as per our priority. Running the MATLAB program number of times it is come to know that the seat acceleration is minimum for the probability of crossover 0.7 and probability of mutation 0.015.

Genetic algorithm is heuristic search technique which works globally to find the minimum value of certain objective. Simulated annealing is also an heuristic search technique but it works locally rather that global like GA. Search of certain goal can be made optimum by combining these two method to Get added benefit of the two.

The number of iteration is taken as 1000. This number of iteration can be varied for different Run.
Seat acceleration is minimum for Run 3. It can be said that to get minimum seat acceleration, take springs with stiffness $K_1$, $K_2$ and $K_3$ and Dampers with damping constant $C_1$, $C_2$ and $C_3$.

In above shown program NG is taken as 100, NP is taken as 100 and number of iteration is taken as 100. This NP, NG and NI can be varied for different Run. Thousand of value for these NP, NG and NI can be taken.

### Table 1: Comparative results obtain for case study 1

| Sr. No. | Design Variable | Genetic Algorithm (GA) | Simulated Annealing (SA) | Hybrid GSA |
|---------|----------------|------------------------|--------------------------|------------|
|         |                | (MATLAB) | (MSC. ADAMS) | (MATLAB) | (MSC. ADAMS) | (MATLAB) | (MSC. ADAMS) |
| NP      |                | 100     | ----       | 100      | ----       | 100      | ----       |
| NG      |                | 100     | ----       | 100      | ----       | 100      | ----       |
| 1       | $K_1$ (N/m)    | 15467.66 | 15467.66  | 43857.05 | 43857.05  | 49591   | 49591   |
| 2       | $C_1$ (N.s/m)  | 6024.91  | 6024.91   | 6594.961 | 6594.961  | 6339    | 6339    |
| 3       | $K_2$ (N/m)    | 47840.83 | 47840.83  | 115384.8 | 115384.8  | 47767   | 47767   |
| 4       | $C_2$ (N.s/m)  | 8097.859 | 8097.859  | 3978.087 | 3978.087  | 10203   | 10203   |
| 5       | $K_3$ (N/m)    | 124462.8 | 124462.8  | 135137.5 | 135137.5  | 87475   | 87475   |
| 6       | $C_3$ (N.s/m)  | 11284.13 | 11284.13  | 11975.25 | 11975.25  | 875     | 875     |
| Objective Function | $\min q(t/m^2)$ | 0.3133 | 0.39       | 0.3499   | 0.421     | **0.2479** | **0.286** |

Figure 3: Convergence of GSA.  
Figure 4: Validated results of GSA.

### 4.2 Case study 2

From the results it is seen that seat acceleration is obtain minimum from Hybrid GSA algorithm. As compare to GA and SA, GSA gives much more desirable minimum objective function. So combining GA and SA the result is improved. From above results it can be said that hybridizing two algorithms proves better than the individuals. We can change the values of number of population and number of generation to get different run. On combining the two techniques a new method evolves i.e. Hybrid Genetic-Simulated annealing algorithm. These all statements are come true after looking the results tabulated below. Hybrid
GSA gives best results than individual GA and SA. The results of MSC.ADAMS come closed with the results of MATLAB. Here it can be said that the results obtain by MATLAB for optimum Ride comfort i.e. lowermost seat acceleration are validated.

Table 2: Comparative results obtain for Case study 2

| Sr. No. | Design Variable | Genetic Algorithm (GA) (MATLAB) | Simulated Annealing (SA) (MATLAB) | Hybrid GSA (MATLAB) | Hybrid GSA (MSC. ADAMS) |
|---------|-----------------|-----------------------------------|-----------------------------------|---------------------|------------------------|
|         |                 | NP 100                            | NG 100                            | 100                 | 100                    |
| 1       | K1(N/m)         | 850.5                             | 754.34                            | 829.09              | 829.09                 |
| 2       | C1(N.s/m)       | 77.53                             | 116.73                            | 111.06              | 111.06                 |
| 3       | K2(N/m)         | 19532                             | 19764                             | 21093               | 21093                  |
| 4       | C2(N.s/m)       | 485.38                            | 471.96                            | 409.57              | 409.57                 |
| 5       | K3(N/m)         | 16672                             | 16332                             | 16328               | 16328                  |
| 6       | C3(N.s/m)       | 943.91                            | 914.4                             | 835.71              | 835.71                 |
|         | Objective Function Min $\ddot{q}$(m/s²) | 1.512                             | 1.5525                            | 1.121               | 1.929                  |
5. Conclusion
Hybrid GSA algorithm is systematically applied to the suspension system of automobile through two different cases. Following conclusions can be sorted:
1. As the Hybrid GSA is integration of two different algorithm, it not only combines their steps but also improves their results. It is seen through both the case studies that the most suitable ride comfort is achieved using Hybrid GSA.
2. A suitable combination of design variables is obtain for maximum ride comfort.
3. MATLAB program can be used to apply it on any automobile suspension system, as here done for MARUTI 800.
4. The suspension system of an automobile can be design considering the obtain parameters combination for desired ride comfort.

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