Improving PID Integrated Active Suspension System by using TLBO optimized parameters

Yash Gandhi
UG student
Department of Industrial Engineering
Pandit Deendayal Petroleum University,
Raisan, Gandhinagar – 382007,India
yash.gie12@sot.pdpu.ac.in

Vedant Mehta
UG student
Department of Industrial Engineering
Pandit Deendayal Petroleum University,
Raisan, Gandhinagar - 382007,India
vedant.mie12@sot.pdpu.ac.in

Mayuri Patel
UG student
Department of Industrial Engineering
Pandit Deendayal Petroleum University,
Raisan, Gandhinagar - 382007,India
mayuri.pie12@sot.pdpu.ac.in

Bhargav Gadhvi
Pandit Deendayal Petroleum University,
Raisan, Gandhinagar – 382007,India
bhargav.g@sot.pdpu.ac.in

Anilkumar Markana
Pandit Deendayal Petroleum University,
Raisan, Gandhinagar – 382007,India
anil.markana@spt.pdpu.ac.in

Abstract

This paper presents the PID controller design for controlling the rattle space parameters of a quarter car active suspension model. By controlling the parameters both the ride comfort and vehicle handling can be improved. PID controller controls the parameters while travelling but using optimized suspension parameters reduces the actuator force to be applied, as well as the rattle space. TLBO (Teacher Learning based algorithm) is used to optimize the parameters i.e., spring constant and damping constant. Quarter car active suspension model has been developed using the Newton's second law of motion with two degrees of freedom. The mathematical model of the car is modeled and simulated using MATLAB/Simulink environment. The simulation is carried out using optimized

suspension parameters and then for the sake of comparison, simulation is also done using non-optimized suspension parameters to draw a clear picture of the decrease in both the effort of actuator force and in the rattle space.

Keywords
Active Suspension, TLBO, PID, Actuator force, Rattle space

1. Introduction
Automobile sector is striving to improve the suspension systems which can fulfil the essential objectives for which it is intended (Guglielmino et al., 2008). The important objectives of suspension system in automotive road vehicles are to provide good ride and handling performance (Gadhvi and Savsani, 2014), to make sure that steering control is maintained during maneuvering, to provide isolation from high frequency vibration from tire excitation, to ensure that vehicle responds favorably to the forces acting on a vehicle such as accelerating forces, lateral cornering forces, braking forces, etc. Thus, suspension geometry should be designed such that it can handle dive, squat and roll forces acting on the body (Gillespie, 1992).

The above mentioned objectives conflict with one another. For instance, increasing the spring's stiffness improves the road handling but decreases the ride comfort and similarly, decreasing the spring stiffness improves ride comfort but decreases road handling properties of the suspension system (Gillespie, 1992). Hence, designing a suspension system is a compromise between road handling and ride comfort.

The suspension system can be classified depending upon which suspension parameters are externally controlled, such as passive suspension in which no parameters are externally controlled, semi-active suspension wherein spring and/or damping constant are modified in response to a Rheo-Magnetic fluid and active suspension systems which include actuators to generate the desired force in the suspension system (Gandhi et al., 2015).

Low and mid-range vehicles house a passive suspension system in which the spring and damping constants are time invariant and thus, do not change according to the forces generated by various road surfaces. Contrary to that, active suspension system includes actuators which generate required force to smoothen out the excitations created by road surfaces. Since active suspension system is controller driven and thus, very expensive, its usage is limited to high-end expensive automobiles.

Enormous amount of work has been published in the field of active suspension system design (Michelberger et al., 1993, Ting et al., 1995, Abdellari et al., 2000, Landau et al., 2003, Priyandoko et al., 2008, Kumar, 2015), development of the vehicle and optimization of suspension system in vehicles (Hac 1985, Gadhvi and Savsani 2014, Ataei 2015, Kumar 2015). Some of these work pertaining to present paper are summarized as follows.

Hac (1985) presented a paper on Suspension optimization of a 2-DOF vehicle model using a stochastic optimal control technique. Wherein, by using stochastic optimal linear control theory and optimal value of the control variable (i.e. suspension force) is calculated. The influences of control force expenditure and the values of the passive suspension elements on the active system performances are studied.

Priyandoko et al. (2008) presented a paper on Vehicle active suspension system using skyhook adaptive neuro active force control. Here, the system developed consists of four feedback control loops, namely proportional-integral (PI) for force tracking of pneumatic actuator, the intermediate skyhook and active force control (AFC) for the compensation of the disturbances and outermost PID for optimum targeted force. A neural network was used to approximate the estimated mass and inverse dynamics of pneumatic actuator in the AFC loop.

A comparison study of two optimization algorithms: Sequential Quadratic Program (SQP) and Genetic Algorithms (GAs) for the optimal design of quarter car vehicle suspensions was presented by Ramë et al. (2010). Through the simulation in MATLAB it will be shown that GA is more powerful tool to find the global optimal point, while local convergence properties has been shown by SQP.

Integrating PID control system in active suspension system has improved ride comfort. Sayel (2012) showed that by using PID controller in active suspension system suspension travel has been reduced by 74.64% for a step input of

0.08m. Senthilkumar (2012) presented similar results. The simulated results prove that, active suspension system with PID control improves ride comfort.

As the paper is pertaining to quarter car, the next section describes the equations and parameters related to it.

2. Mathematical Modelling

To simplify the calculations quarter car model is considered. Quarter car model consist of the 1/4th of the total mass of the vehicle. It can cover important characteristics of a full model. Quarter car model involves study of a single wheel and corresponding suspension components. It is the most simplified model because it does not involve other force components like pitch, roll and yaw movement.

The primary objective of this study is to optimize the suspension parameters, i.e., spring and damping constant. Since the active suspension is considered, using optimized values of spring and damping constant will minimize the actuator force to be applied to reduce the vibrations. Moreoever, optimization is best done on a quarter car model only because it has a relatively simpler mathematical model for the computers to deal with. As shown in figure 1, the quarter car model consists of two different masses and two sets of spring and damper. Sprung mass (m_s) is the mass supported above the suspension and it consists mainly of the chassis and body weight (1/4th of the total weight because it is a quarter car model). Unsprung mass (m_{us}), is the weight below the suspension. It includes weight of components such as wheel, wheel bearings, brake rotors and drive shaft. As shown in the figure, vertical displacement of masses m_s and m_{us} are z_s and z_{us} respectively. The road height which is in contact with the road is z_r. The suspension of the car located between the sprung and unsprung mass is modelled as the spring coefficient k_s (of the suspension) and damping constant c_s (of the suspension). Elastic and damping properties of tire are assigned as k_t (spring coefficient) and c_t (damping coefficient). Springs and dampers are characterized as linear system. One more component is modelled between sprung and unsprung mass, namely u_a which represents the actuator force applied.

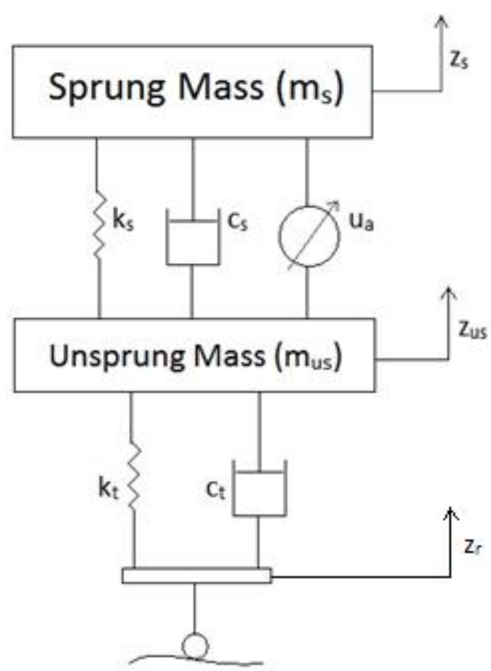

Figure 1: Quarter Car Active Suspension Model

Unlike passive suspension elements, the force created by this actuator does not depend on direct velocity or relative displacement, it also depends on a feedback controller working based on a special control strategy. The main aim of the active suspension system is to reduce the excitation of sprung mass so as to increase the ride comfort. At higher frequencies (more than the natural frequency of the body) active suspension element is rendered useless and wheel motion is controlled only by passive elements of the suspension.

The mathematical model of motion of the masses is given as follows:

$$m_s\ddot{z}_s = -k_s(z_s - z_{us}) - c_s(\dot{z}_s - \dot{z}_{us}) + u_a \tag{1}$$

$$m_{us}\ddot{z}_{us} = k_s(z_s - z_{us}) + c_s(\dot{z}_s - \dot{z}_{us}) - k_t(z_{us} - z_r) - c_t(\dot{z}_{us} - \dot{z}_r) - u_a \tag{2}$$

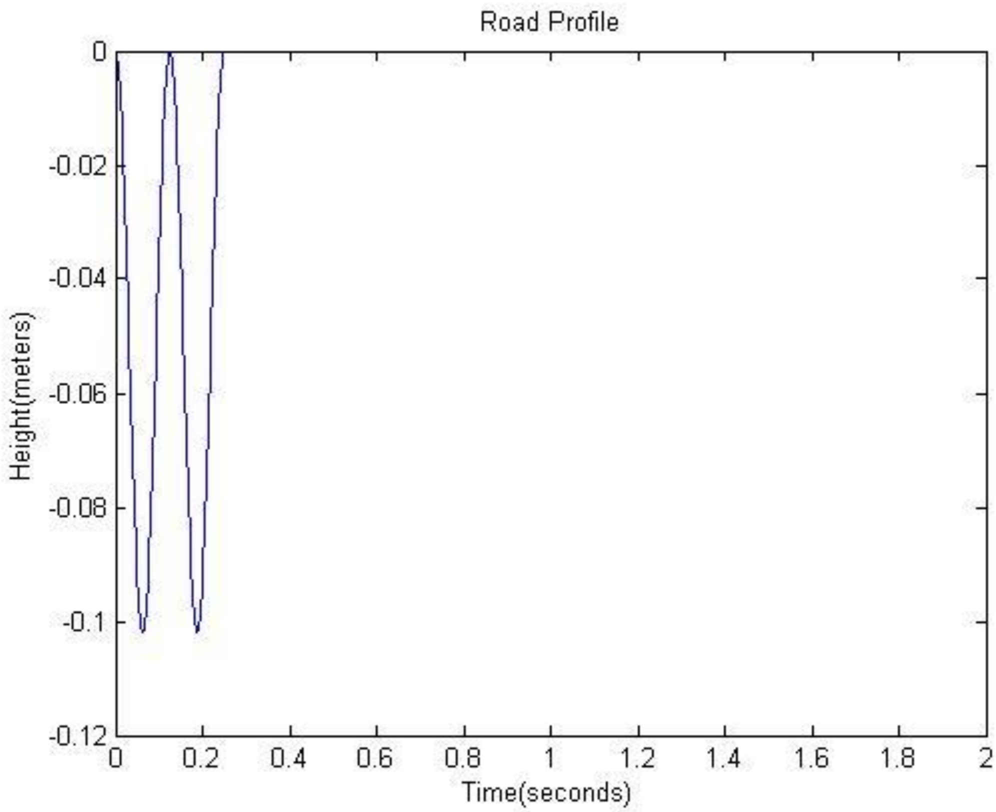

Figure 2: Road Profile

The road profile which is considered in the paper is shown in Figure 1 and the parameters used are given in Table 1.

Table 1: Quarter Car parameters

Symbol	Name	Value
m_s	Sprung mass	327 kg
m_{us}	Un-sprung mass	116 kg
k_s	Suspension stiffness constant (non-optimized)	15000 N/m
k_t	Tire stiffness constant	256740 N/m
c_s	Suspension damping coefficient (non-optimized)	2000 kg/s
c_t	Tire damping coefficient	730 kg/s

3. Teaching-Learning Based Optimization (TLBO)

A new efficient optimization algorithm, called 'Teaching–Learning-Based Optimization (TLBO)' (Rao et al. 2011, Rao et al. 2012), is used in this work for the optimization of suspension design problems. This method works on the effect of influence of a teacher on learners. TLBO is a population-based method where it uses various solutions generated from each population to obtain a global solution. It consists of two phases: the first phase being 'Teacher phase' which means learning from the teacher and the other phase being the 'Learner Phase', which means learning by interaction among the learners.

TLBO shows better performance over other nature-inspired optimization methods like Artificial Bee Colony (ABC), Particle Evolutionary Swarm Optimization (PESO), Cultural Differential Evolution (CDE) etc. for the constrained benchmark functions for different performance criteria, such as success rate, mean solution, average number of function evaluations required, convergence rate, etc. (Rao et al. 2011, Rao et al. 2012).

4. Control Methodology

PID (Proportional-Integral-Derivative) control is the most basic and conventional control technique used by control community. Rattle space (relative displacement of sprung and un-sprung mass) is process control variable. According to the set point, error is calculated and proportional term controls the rattle space in proportion to the current error. A more complex control i.e., derivative term, considers the rate of change of error and thus controls the rattle space depending on how fast the error is approaching zero. Finally, integral control, using the past accumulated errors, checks whether the rattle space is too high or too low and thus set the rattle space proportional to the past errors. PID control is given as follows,

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t) \tag{3}$$

Where:

- K_p: Proportional gain
- K_i: Integral gain
- K_d: Derivative gain
- e: Error = SP-PV = Set point – Process variable
- t: Time on instantaneous time (the present)
- τ: Variable of integration; takes on values from time 0 to present t

PID tuning is the process of finding the values of proportional (K_p), integral (K_i), and derivative gains (K_d) of a PID controller to achieve control action designed to meet specific requirements and desired performance.

The next section will show the comparison in the amount of actuator force and rattle space between optimized values and random values of the spring and damping constant from the feasible range of the respective values for a PID integrated active suspension model.

5. Simulation Results

TLBO Algorithm was carried out for 5 runs each with 100 iterations or generations and population size was kept 50. Out of 5 the best run results were chosen for improving the controller performance. The results obtained are shown in tables below.

Both TLBO optimized passive suspension parameters and un-optimized suspension parameters are shown in table 2 and 3 respectively.

Table 2: Optimization Values

Symbol	**Name**	**Range for optimization**	**Optimized value**
k_s	Suspension stiffness constant	10000-50000	10000 N/m
c_s	Suspension damping coefficient	1000-5000	4921.669 kg/s

Table 3: Non -Optimization Values

Symbol	**Name**	**Range for optimization**	**Non-Optimized value**
k_s	Suspension stiffness constant	10000-50000	15000 N/m
c_s	Suspension damping coefficient	1000-5000	2000 kg/s

Figure 3 shows the plot of convergence for TLBO algorithm. It can be seen that after few iterations the sprung mass acceleration becomes constant. This shows that TLBO is suitable for the optimization problem of vehicle active suspension system. It should be noted that figure 3 shows the convergence plot of the best run out of 5 conducted runs.

By using the optimized values in Table 2 for active suspension system and non-optimized value in Table 3, a comparison was carried out. The MATLAB file for the actuated force required was simulated for the quarter car constants (sprung and un-sprung masses, suspension's and tire's stiffness and damping co-efficient values) these values are listed in Table 1 and results were obtained as shown in figure 4 and 5.

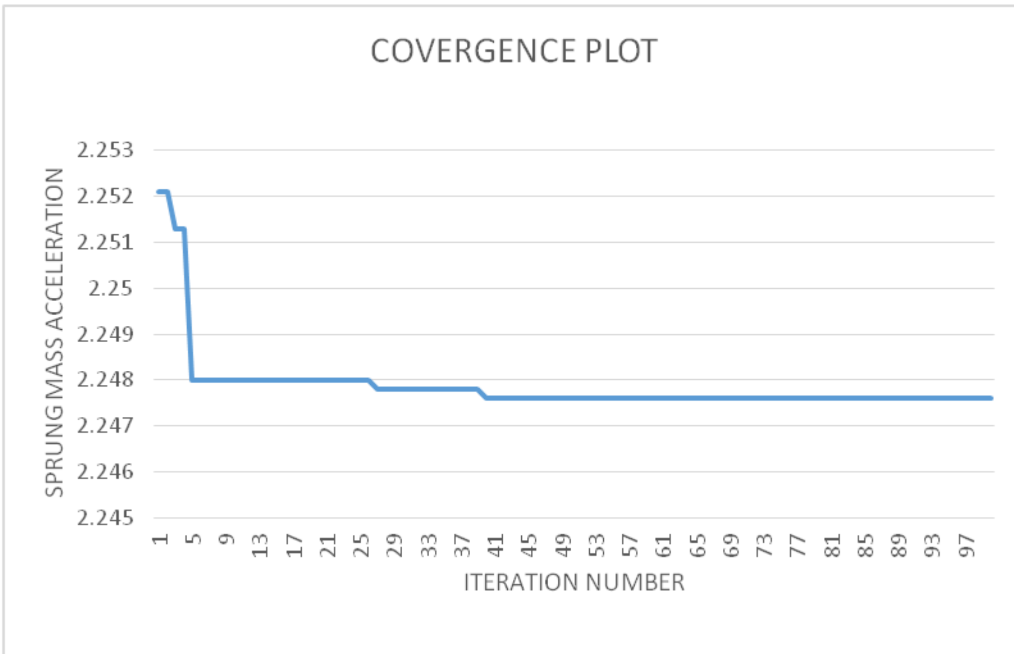

Fig. 3 Convergence Plot for TLBO

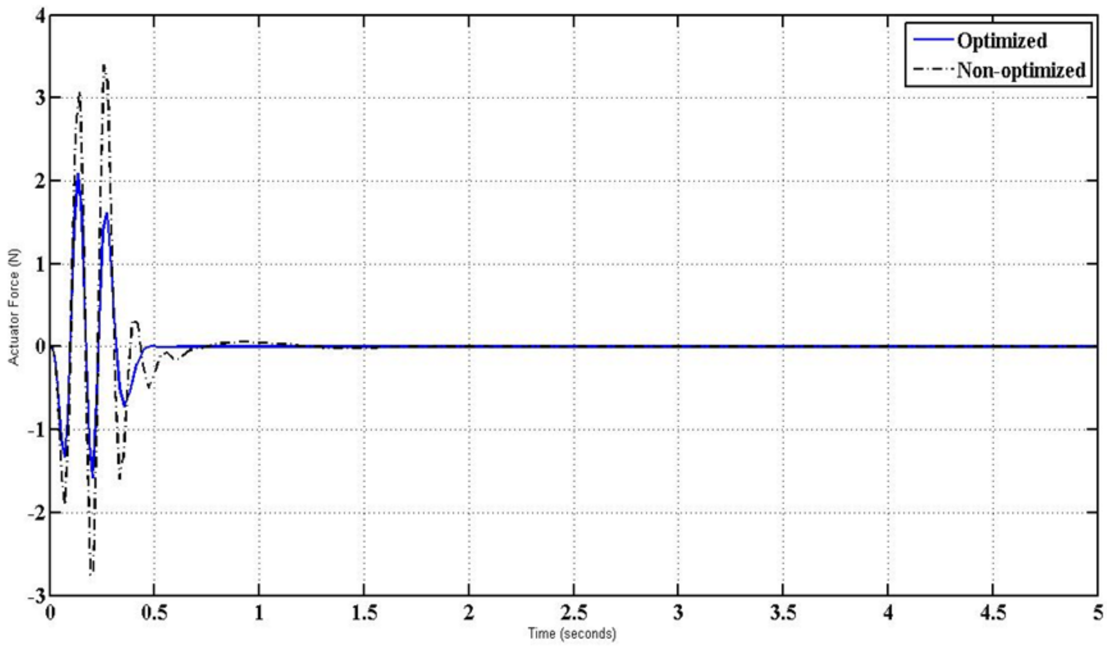

Fig. 4 Actuator force to be applied in case of optimized and non-optimized values

As can be seen in Figure 4, the peak values of actuator force has decreased when optimized values were used. The force required in optimized values is reduced to 36% than compared to the force required in non-optimized values.

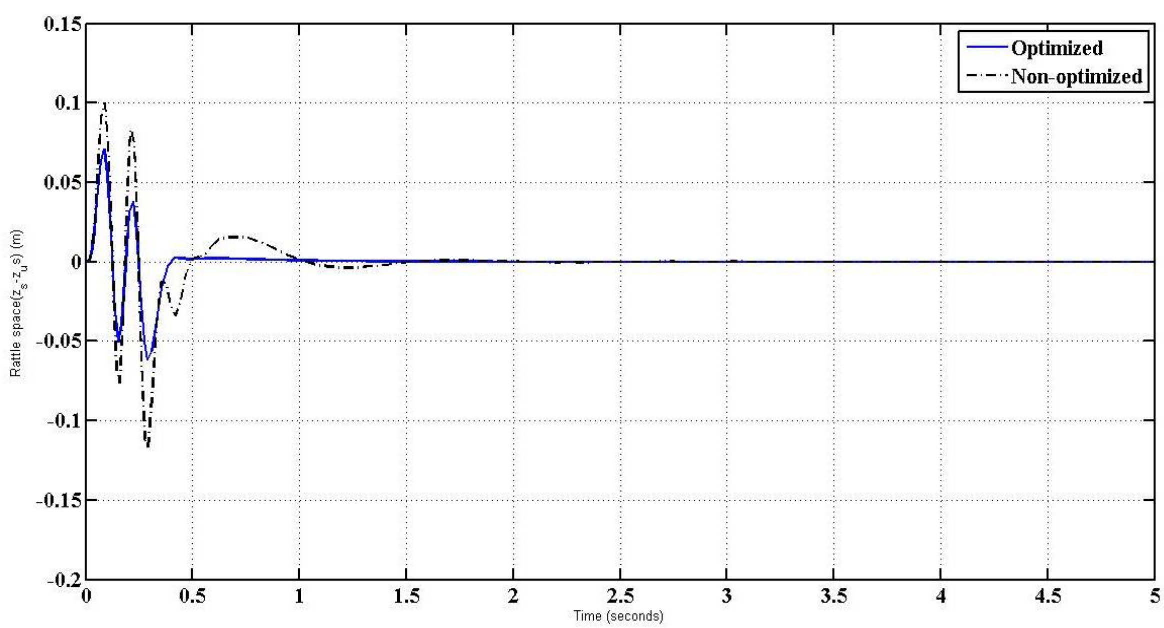

Fig. 5 Rattle space in case of optimized and non-optimized values

The Figure 5 shows the decrease in suspension travel. The suspension travel reduced to 41% when we used optimized values instead of non-optimized values.

So, it can be concluded from the results that there is a significant decrease in actuator force as well as rattle space. Thus decreasing the power consumption required for the actuator and increasing the ride comfort.

Acknowledgements

The authors are thankful to the Office of Research and Sponsored Program, Pandit Deendayal Petroleum University for providing funding support to the project reference no .ORSP/R&D/SRP/2014/VMBG. The authors are also thankful to icreate (International Centre for Entrepreneurship and Technology), Ahmedabad for the research grant to support this project. The authors would also like to sincerely thank Dr. Vimal Savsani for his guidance.

References

Abdellari, E, Mehdi, D, and Saad, M, On the design of active suspension system by H∞ and mixed H 2/H∞: An LMI approach, *American Control Conference, Proceedings of the IEEE*, Vol. 6, pp. 4041-4045, 2000.

Ataei, M, Asadi, E, Goodarzi, A, Khajepour, A, and Khamesee, M, Multi-objective optimization of a hybrid electromagnetic suspension system for ride comfort, road holding and regenerated power, *Journal of Vibration and Control*, 1077546315585219, 2015.

Gadhvi, B, and Savsani, V, Passive Suspension Optimization Using Teaching Learning Based Optimization and Genetic Algorithm Considering Variable Speed Over a Bump, *ASME 2014 International Mechanical Engineering Congress and Exposition*, Vol. 4A, pp. V04AT04A018-V04AT04A018, 2014.

Gandhi, Y, Patel, M, Mehta V, Gadhvi, B, and Markana A, Control Design and Analysis of Active Vehicle Suspension Using Integral Pole Placement Controller, *Journal of Aeronautical and Automotive Engineering (JAAE)*; Volume 2, Number 1, January-March, 2015 pp. 33-37. Krishi Sanskriti Publications.

Gillespie T, *Fundamentals of Vehicle Dynamics*, Society of Automotive Engineers International, Warrendale, 1992.

Guglielmino, E., Sireteanu, T., Stammers, C. W., Ghita, G., and Giuclea, M., *Semi-active suspension control: improved vehicle ride and road friendliness*, Springer Science & Business Media, Girona, Spain, 2008.

Hac, A., Suspension Optimization of a 2-DOF Vehicle Model Using a Stochastic Optimal Control Technique, *Journal of sound and vibration*, Vol. 100, No.3, pp. 343-57, 1985.

Kumar, M, Genetic algorithm-based proportional derivative controller for the development of active suspension system, *Information Technology and Control*, Vol. 36, No. 2, 2015.

Landau, I, Karimi, A, Miŝković, L, and Prochazka, H, Control of an active suspension system as a benchmark for design and optimisation of restricted-complexity controllers. *European Journal of Control*, Vol. 9, No. 1, pp. 3-12, 2003.

Michelberger, P, Palkovics, L, and Bokor, J, Robust design of active suspension system, *International Journal of Vehicle Design*, Vol. 14, No. 2-3, pp. 145-165, 1993.

Priyandoko, G., Mailah, M., and Jamaluddin, H., Vehicle Active Suspension System Using Skyhook Adaptive Neuro Active Force Control, *Mechanical Systems and Signal Processing*, Vol. 23, no. 3, pp. 855-868, 2009.

Ramë, L., Ahmet, S., Mirlind, B., and Mehmet, Q., Optimal design of quarter car vehicle suspension system ,*14th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology"* TMT 2010, Mediterranean Cruise, 2010.

Rao, RV., Savsani, VJ., and Vakharia, DP., Teaching-learning-based optimization: a novel method for constrained mechanical design optimization problems, *Computer-Aided Design*, Vol. 43, no. 3, pp. 303–315, 2011.

Rao, R, Savsani, V, and Vakharia, D, Teaching–learning-based optimization: an optimization method for continuous non-linear large scale problems. *Information Sciences*, Vol. 183, No. 1, pp. 1-15, 2012.

Sayel, M, F., Constructing Control System for Active Suspension System, *Contemporary Engineering Sciences*, Vol. 5, no. 4, pp. 189 – 200, 2012.

Ting, C, Li, T, and Kung, F, Design of fuzzy controller for active suspension system. *Mechatronics*, Vol. 5, No. 4, pp. 365-383, 1995.

Biography

Yash Gandhi is pursuing B. Tech in Industrial engineering in Pandit Deendayal Petroleum University. He plans to pursue Masters in the field of Industrial engineering after completing graduation. . He is the author of paper relating to active suspension system. His area of interest is vehicle dynamics and optimization. He has given financial assistance for Research project under Student Research Program and icreate entitled “Estimating the profiles of speed bump and potholes through experimental Quarter Car setup.” The project is been carried out under the guidance of Mr. Bhargav Gadhvi.

Mayuri Patel is pursuing B. Tech in Industrial engineering in Pandit Deendayal Petroleum University. She has given financial assistance for Research project under Student Research Program and icreate entitled “Estimating the profiles of speed bump and potholes through experimental Quarter Car setup.” The project is been carried out under the guidance of Mr. Bhargav Gadhvi. She has also co-authored a paper related to active suspension system with pole placement controller. Mayuri is a member of ASQ. Her area of interest is quality control, optimization and vehicle dynamics.

Vedant Mehta is pursuing B. Tech in Industrial engineering in Pandit Deendayal Petroleum University. He plans to pursue Masters in the field of Industrial engineering after completing graduation. He is a member of SAE INDIA and has been a part of BAJA-SAEINDIA 2015. He has also co-authored a paper relating to active suspension system. His area of interest is vehicle dynamics and optimization. He has given financial assistance for Research project under Student Research Program and icreate entitled “Estimating the profiles of speed bump and potholes through experimental Quarter Car setup.” The project is been carried out under the guidance of Mr. Bhargav Gadhvi.

Bhargav Gadhvi is a lecturer in Mechanical Engineering Department, Pandit Deendayal Petroleum University, Gandhinagar, India. He pursued Master of Technology in Mechanical Engineering and has published 7 research papers in the field of optimization, vehicle dynamics and Robotic Excavation. He has received two research grants in the field of sustainable vehicle technologies. His current domains of research are: Improved Multi-Objective Evolutionary Algorithms (MOEA) and its application to semi active vehicle suspension control system; convergence analysis of various recently developed meta-heuristic optimization methods.

Anilkumar Markana received B.E. (Instrumentation & Control) from Gujarat University and M.Tech in Systems & Control Engineering from Indian Institute of Technology, Bombay. He is currently working as a lecturer at Pandit Deendayal Petroleum University, Gandhinagar. His area of interest is Multi Objective optimization based on Model Predictive Control.