SEMI ACTIVE SUSPENSION SYSTEM USING SKY HOOK CONTROLLER WITH PARTICLE SWARM OPTIMIZATON

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Dedicated to

My family, my colleagues

&

Special dedication to

My beloved parents

Who did not live to share the happiness in my achievements

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ABSTRACT

Skyhook control technique is the most common control algorithm applied in various engineering applications. Also, particle swarm optimization (PSO) is extensively applied in various optimization problems. This paper introduces an investigation into the use of a PSO algorithm to tune the Skyhook controller for a semi-active vehicle suspension system incorporating magneto-rheological (MR) damper to improve the ride comfort and vehicle stability. The proposed suspension system consists of a system controller that determine the desired damping force using a Skyhook controller tuned using PSO, and a continuous state damper controller that estimate the command voltage that is required to track the desired damping force. The PSO technique is applied to solve the nonlinear optimization problem to find the Skyhook controller gains by identifying the optimal problem solution through cooperation and competition among the individuals of a swarm. A mathematical model of a two degree-of-freedom MR-damped vehicle suspension system is derived and simulated using Matlab/SIMULINK software. The proposed PSO Skyhook controlled suspension is compared to the passive suspension systems. System performance criteria are evaluated in both time and frequency domains, in order to quantify the success of the proposed suspension system. The simulated results reflect that the proposed PSO Skyhook controller of the MR-damped vehicle suspension offers a significant improvement in ride comfort and vehicle stability.

ABSTRAK

Teknik kawalan *Skyhook* adalah algoritma kawalan yang biasa digunakan dalam pelbagai aplikasi kejuruteraan. Pengoptimuman kawanan zarah *(PSO)* juga digunakan dengan meluas dalam pelbagai masalah pengoptimuman. Tesis ini memperkenalkan kajian terhadap penggunaan algoritma *PSO* untuk menala pengawal *Skyhook* untuk sistem penggantungan kenderaan semi-aktif yang menggabungkan peredam *magneto-rheological (MR)* dalam meningkatkan keselesaan perjalanan dan kestabilan kenderaan. Sistem penggantungan yang dicadangkan terdiri daripada pengawal sistem yang menentukan daya redaman yang dikehendaki menggunakan pengawal *Skyhook* yang ditala menggunakan (*PSO-Skyhook*) dan pengawal peredam berterusan yang menganggarkan voltan *command* yang diperlukan untuk mengesan daya redaman yang dikehendaki. Teknik *PSO* digunakan untuk menyelesaikan masalah pengoptimuman tak linear bagi mencari nilai pekali pengawal *Skyhook* dengan mengenal pasti penyelesaian masalah yang optimum melalui kerjasama dan persaingan secara individu dalam kumpulan *swarm*. Model matematik dua darjah kebebasan untuk sistem penggantungan kenderaan secara *MR*-teredam dihasilkan dan disimulasi menggunakan perisian *Matlab / SIMULINK*. Sistem penggantungan kenderaan yang dikawal *PSO-Skyhook* dibandingkan dengan sistem penggantungan pasif. Kriteria prestasi sistem dinilai dalam domain masa dan frekuensi, untuk mengukur keberhasilan sistem penggantungan yang dicadangkan. Keputusan simulasi menunjukkan bahawa pengawal *PSO-Skyhook* yang dicadangkan dengan sistem penggantungan secara *MR*-teredam menawarkan peningkatan yang ketara dalam keselesaan pemanduan dan kestabilan kenderaan.

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LIST OF SYMBOLS

a - Ratio of post yield to pre yield
c_1 - Weight factors
c_s - Damping coefficient
c_{sky} - Coefficient of skyhook damping
$F(t)$ - Restoring force
F_{max} - Maximum damping force
F_y - Yield force
$f(t)$ - Excitation force
k_s - Spring stiffness
k_t - Tire stiffness
l - Axial dimension of magnetic choke
m_s - Sprung mass
m_u - Un-sprung mass
p_1 - Upper chamber pressure of MR damper
p_2 - Lower chamber pressure of MR damper
$rand1$ - Random number between 0 and 1
r - Piston radius
u_a - Actuator force
$u(t)$ - Displacement
u_y - Yield displacement
v_i^k - Velocity of particle i in k^{th} iteration
w - Weight parameter
x_w - Wheel displacement
x_i^k - Position of particle i in k^{th} iteration
z_r - Road profile input

$z(t)$ - Dimensionless parameter

$\dot{x}_s$ - Velocity of car body

$\dot{x}_w$ - Wheel velocity

τ - Shear stress in magnetic choke

LIST OF ABBREVIATIONS

A/D - Alternate to direct current
B.C - Before century
D/A - Direct to alternate current
DOF - Degree of freedom
MPH - Mile per hour
MR - Magneto-rheological
MSE - Mean square error
PID - Proportional integral differential
PSO - Particle swarm optimization

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Suspension System

It is well known that comfort ability is one of an important criterion in designing a car suspension system. The purposes of the car suspension are to minimize the car body vibration caused by the road surface, to support the vehicle body and keeping the vehicle occupant in comfortable and for vehicle handling (Xiangying, 2004). Most of researches nowadays towards suspension system to achieve quality vehicle ride and handling (Fischer *et al*., 2004). The suspension system of ground vehicle is located between the vehicle body and the vehicle wheels, and the components of suspension depend upon the type of suspension system (Fischer *et al*., 2004). The vehicle suspension system consists of two type's namely passive and active suspension system.

The conventional suspension system which also known as a passive suspension system consists of a spring fixed parallel with a damper and it is located between un sprung mass and sprung mass. It has been used for the entire vehicle around the world since 1906 and it was found by a young man name William rush'. Meanwhile, a new advanced suspension system which also known as an active suspension system was design seriously by Lotus Garage, Lotus 92 in early of the 1980s. The difference between these two types of suspension systems is the conventional system is more retarded with seeming casualness as compared to the active system.

1.2 Problem Statement

The passive suspension system is an open loop control system. It is only designed to achieve certain condition only. The characteristic of passive suspension is fixed and cannot be adjusted by any mechanical part. The problem of passive suspension, if it designs heavily damped or too hard suspension it will transfer a lot of road input or throwing the car on unevenness of the road. Then, if it lightly damped or soft suspension it will give reduce the stability of vehicle in turns or change lane or it will swing the car. Therefore, the performance of the passive suspension depends on the road profile.

In another way, the semi active suspension system can give better performance of suspension by having force actuator, which is a close loop control system. The force actuator is a mechanical part that added inside the system that control by the controller. The controller will calculate either add or dissipate energy from the system with the help of sensors as an input. Sensors will give the data of road profile to the controller.

1.3 Objectives of the Project

The objectives of this project are to model and control a semi active suspension system using sky hook controller with particle swarm optimization and to compare the performance for both semi active and passive suspension system.

1.4 Scope of the Project

The project scope is very vital to ensure an objective of the project is achieved. Generally, the list of the project scope is used as a guide for the project research. The scopes of this project can be refer to Figure 1.1 and summarized as follows:

I. Literature review of semi active suspension system, semi active suspension system with sky hook controller and semi active suspension system equipped with particle swarm optimization.

II. Modelling and simulation of Quarter Car Model for Passive and semi active suspension system using Matlab/SIMULINK.

III. Development of Skyhook controller within Matlab/SIMULINK for semi active suspension system using Particle Swarm Optimization to tune Skyhook damping values.

IV. Analyse, verify and validate the performance of develop semi active suspension system using Skyhook with Particle Swarm Optimization in Matlab/SIMULINK.

V. Comparison both semi active suspensions equipped with controller and passive suspension system in term of body displacement, body acceleration, wheel displacement and suspension travel.

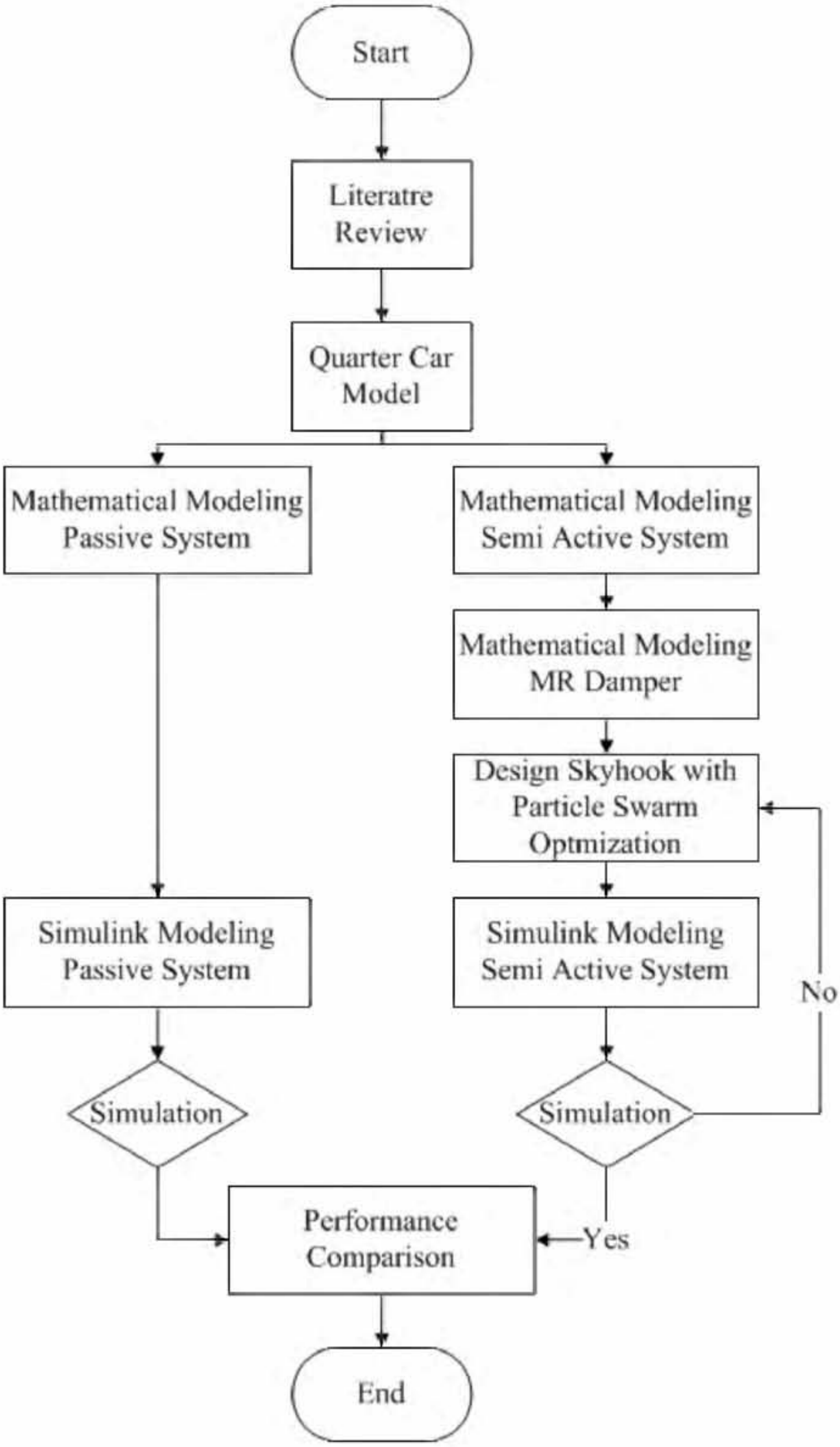

Figure 1.1 Flow Chart of Research Methodology

REFERENCE

Ali, M.M. & Kaelo, P. (2008). Improved Particle Swarm Algorithms for Global Optimization. *Applied Mathematics and Computation*, 196(2), pp.578–593.

Anon. (2014). Magneto-Rheological (MR) Fluid. *http://www.mrfluid.com* [Accessed April 25, 2015].

Bouc, R. (1967). Forced Vibration of Mechanical Systems With Hysteresis. *4th Conference on Nonlinear Oscillations*, p.315.

Charalampakis, A. E. & Koumousis, V.K. (2008). On the Response and Dissipated Energy of Bouc-Wen Hysteretic Model. *Journal of Sound and Vibration*, 309(3-5), pp.887–895.

Ciuprina, G., Ioan, D. & Munteanu, I. (2002). Use of Intelligent Particle Swarm Optimization in Electromagnetics. In *IEEE Transactions on Magnetics*. pp. 1037–1040.

Clerc, M. & Kennedy, J. (2002a). The Particle Swarm - Explosion, Stability, and Convergence in a Multidimensional Complex Space. *IEEE Transactions on Evolutionary Computation*, 6(1), pp.58–73.

Clerc, M. & Kennedy, J. (2002b). The Particle Swarm - Explosion, Stability, and Convergence in a Multidimensional Complex Space. In *IEEE Transactions on Evolutionary Computation*. pp. 58–73.

Constantinou, M., Mokha, A. & Reinhorn, A. (1990). Teflon Bearings in Base Isolation II: Modeling. In *Journal of Structural Engineering*, 116, pp.455-474.

Dimopoulos, G.G. (2007). Mixed Variable Engineering Optimization based on Evolutionary and Social Metaphors. In *Computer Methods in Applied Mechanics and Engineering*. pp. 803–817.

Dimou, C.K. & Koumousis, V.K. (2009). Reliability-Based Optimal Design of Truss Structures Using Particle Swarm Optimization. In *Journal of Computing in Civil Engineering*. pp. 100–109.

Dominguez, A., Sedaghati, R. & Stiharu, I. (2008). Modeling and application of MR Dampers in Semi Adaptive. *Computers and Structures*, 86(3), pp.407–415.

Fischer, D. & Isermann, R. (2004). Mechatronic Semi Active and Active Vehicle Suspensions. *Control Engineering Practice*, 12(11), pp.1353–1367.

Foliente, G.C. (1995). Hysteresis Modeling of Wood Joints and Structural Systems. *Journal of Structural Engineering*, 121(6), pp.1013–1022.

Fourie, P.C. & Groenwold, A. A. (2002). The Particle Swarm Optimization Algorithm in Size and Shape Optimization. *Structural and Multidisciplinary Optimization*, 23(4), pp.259–267.

Ge, H., Liang, Y. & Marchese, M. (2007). An Improved Particle Swarm Optimization based Dynamic Recurrent Neural Network for Identifying and Controlling Nonlinear Systems Optimization-Based Dynamic Recurrent Neural Network for Identifying and Controlling Nonlinear Systems. In *Comput Struct*. pp. 1–30.

Gholizadeh, S. & Salajegheh, E. (2009). Optimal Design of Structures Subjected to Time History Loading by Swarm Intelligence and an Advanced Metamodel. *Computer Methods in Applied Mechanics and Engineering*, 198(37-40), pp.2936–2949.

Guo, S. (2005). Analysis of an Isolation System with Magnetorheological Damper. *International Journal of Nonlinear Sciences and Numerical Simulation*, 6(1), pp.75–79.

Guo, S. (2006). Dynamic Modeling of Magnetorheological Damper Behaviors. *Journal of Intelligent Material Systems and Structures*, 17(1), pp.3–14.

Hao, L. (1997). The Noncatalytic C-Terminal Segment of the T Cell Protein Tyrosine Phosphatase Regulates Activity via an Intramolecular Mechanism. *Journal of Biological Chemistry*, 272(46), pp.29322–29329.

Hrovat, D. (1997). Survey of Advanced Suspension Developments and Related Optimal Control Applications,. *Automatica*, 33(10), pp.1781–1817.

Ismail, M., Ikhouane, F. & Rodellar, J. (2009). The hysteresis Bouc-Wen model, a Survey. *Archives of Computational Methods in Engineering*, 16(2), pp.161–188.

Kennedy, J. & Eberhart, R. (1995). Particle swarm optimization. In *Proceedings of ICNN'95 - International Conference on Neural Networks*. pp. p.1942–8.

Kruczek, A. & Stribrsky, A. (2004). A full Car Model for Active Suspension - Some Practical Aspects. *Proceedings of the IEEE International Conference on Mechatronics. ICM '04.*, pp.41–45.

Kwok, N.M. (2006). A novel Hysteretic Model for Magnetorheological Fluid Dampers and Parameter Identification using Particle Swarm Optimization. *Sensors and Actuators A: Physical*, 132(2), pp.441–451.

Liu, B. (2006). Directing Orbits of Chaotic Systems by Particle Swarm Optimization. *Chaos, Solitons and Fractals*, 29(2), pp.454–461.

Liu, L., Liu, W. & Cartes, D. A. (2008). Particle Swarm Optimization-Based Parameter Identification Applied to Permanent Magnet Synchronous Motors. In *Engineering Applications of Artificial Intelligence*. pp. 1092–1100.

Liu, W. (2010). Experimental Modeling of Magneto-Rheological Damper and PID Neural Network Controller Design. *2010 Sixth International Conference on Natural Computation*, (Icnc), pp.1674–1678.

M. Valasek, M. Novak, Z. Sika, and O.V. (1997). Extended Ground-Hook New Concept of Semi-Active Control Of Truck's Suspension. *Journal Vehicle System Dynamics.*, 27(5), pp.289–303.

Ma, F. (2004). Parameter Analysis of the Differential Model of Hysteresis. *Journal of Applied Mechanics*, 71(3), p.342.

Majhi, B. & Panda, G. (2010). Development of Efficient Identification Scheme for Nonlinear Dynamic Systems using Swarm Intelligence Techniques. In *Expert Systems with Applications*. pp. 556–566.

Marano, G.C. & Sgobba, S. (2007). Stochastic Energy Analysis of Seismic Isolated Bridges. *Soil Dynamics and Earthquake Engineering*, 27(8), pp.759–773.

Millonas, M.M. (1993). Swarms, Phase Transitions, and Collective Intelligence. In *Langton CG, editor. Artificial life, vol. III. Reading, MA: Addison Wesley*. p. 30.

Priyandoko, G., Mailah, M. & Jamaluddin, H. (2009). Vehicle Active Suspension System using Skyhook Adaptive Neuro Active Force Control. *Mechanical Systems and Signal Processing*, 23(3), pp.855–868.

Qazi, A.J. (2013). Optimization of Semi-active Suspension System Using Particle Swarm Optimization Algorithm. *AASRI Procedia*, 4, pp.160–166.

Rashid, M.M. (2011). Analysis and Experimental Study of Magnetorheological based Damper for Semiactive Suspension System using Fuzzy Hybrids. *IEEE Transactions on Industry Applications*, 47(2), pp.1051–1059.

Riahi, A., Balochian, S. & Branch, G. (2012). Fuzzy and Sliding Mode Control Design for Vehicle Ride Performance. , (May), pp.37–41.

Schutte, J.F. & Groenwold, A. A. (2003). Sizing Design of Truss Structures using Particle Swarms. *Structural and Multidisciplinary Optimization*, 25(4), pp.261–269.

Senthil, M. & Vijayarangan, S. (2007). Analytical and Experimental Studies on Active Suspension System of Light Passenger Vehicle to Improve Ride Comfort. , 3(3), pp.34–41.

Shuqi Guo, Shaopu Yang and Cunzhi Pan. (2005). The Effects of Hysteretic and Bi-Viscous Behaviors on Vehicle Suspension System with Magnetorheological Damper. In *International Conference on Mechanical Engineering and Mechanics*. pp. 1465–1470.

Sobieszczanski-Sobieski, J. & Venter, G. (2002). Multidisciplinary Optimization of a Transport Aircraft Wing using Particle Swarm Optimization. *Struct Multidiscip Optim 2004*, 26(1-2)(121-31).

Ram Mohan Rao, T., Venkata Rao, G. (2010). Analysis of Passive and Semi Active Controlled Suspension System for Ride Comfort in an Omnibus Passing Over a Speed Bump. *IJRRAS*, 5(October), pp.7–17.

Wang CH, W.Y. (2000). Evaluation of Pre-Northridge Low Rise Steel Buildings, Part I. Modeling. *J Struct Eng – ASCE*, 126(10)(1160), p.8.

Wen, Y.-K. (1976). Method for Random Vibration of Hysteretic Systems. *Journal of the Engineering Mechanics Division*, 102(2), pp.249–263.

Wilke, D.N., Kok, S. & Groenwold, A. A. (2007). Comparison of Linear and Classical Velocity Update Rules in Particle Swarm Optimization: Notes on Scale and Frame Invariance. *International Journal for Numerical Methods in Engineering*, 70(8), pp.985–1008.

Xiangying, R.Y. and B. (2004). An Automobile Semi-Active Suspension System using Neural Network Control and Simulation. *Proceedings of the 2004 International Conference on Intelligent Mechatronics and automation*, (August), pp.4–7.

Yao, G.Z. (2002). MR Damper and Its Application for Semi Active Control of Vehicle Suspension System. *Mechatronics*, 9(1), pp.95–973.

Ye, M. (2006). Parameter Identification of Dynamical Systems Based on Improved Particle Swarm Optimization. *Convergence*, 344, pp.351 – 360.

Yi, K. & Song, B.S. (2005). A New Adaptive Sky Hook Control of Vehicle Semi Active Suspensions. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 213(3), pp.293–303.