International Conference on Recent Advancement in Science & Technology- 2020
(ICRAST-2020)

A Review on Sliding Mode Control Mechanism for Reducing Vibrations in Vehicles

Shiv Gopal, Vinay Kumar Singh
Dept of Mechanical Engineering,
SR Institute of Management and Technology, Lucknow, India
gopal21sp@gmail.com, vinaysingh.singh498@gmail.com

***Abstract*-The vehicle suspension supports and isolates the vehicle body and payload from road vibrations because of surface roughness by maintaining a governable damping traction force between tires and paved surface. In trendy luxury vehicles semi active suspension are providing both reliability and accuracy that has increased the traveller ride comfort with less power demand. In this paper we have projected the design of a hybrid system having a mix of skyhook theory with fuzzy logic control and applied on a semi-active vehicle suspension for its ride comfort sweetening. A 2 degree of freedom dynamic model is simulated victimisation Matlab/Simulink for a vehicle equipped with semi-active suspension with targeted on the passenger's ride comfort performance.**

Keywords-Fuzzy inference system, vibration control, sliding surface, error control

1. Introduction:

The ride comfort is one of the most important characteristics for a vehicle suspension system. By reducing the vibration transmission and keeping proper tire contacts, the active and semi-active suspension system are designed and developed to achieve better ride comfort performance than the passive suspension system. The active suspension is designed to use separate actuators which can exert an independent force on the suspension, this action is to improve the suspension ride comfort performance.

Suspension system is one of the important components of a vehicle, which plays a crucial role in handling the performance and ride comfort characteristics of a vehicle. A suspension system acts as a bridge between the occupants of a vehicle and the road on which it rides. It has two main functionalities. One is to isolate the vehicle body with its passengers from external disturbance inputs, which mainly come from irregular road surfaces. It always relates to riding quality. The other is to maintain a firm contact between the road and the tires to provide guidance along the track. This is called handling performance.

In a conventional passive suspension system, which is composed of only springs and dampers, a tradeoff is needed to resolve the conflicting requirements of ride comfort and good handling performance. The reason is that stiff suspension is required to support the weight of the vehicle and to follow the track; on the other hand, soft suspension is needed to isolate the disturbance from the road. Hence, there exists a significantly growing interest in the design and control of active suspension systems for automotive engineers and researchers over the past three decades. An active suspension system is characterized by employing certain kinds of suspension force generation, such as pneumatic, magneto-rheological, or hydraulic actuators. Practical applications of active suspension systems have been facilitated by the development of microprocessors and electronics since the middle 1980s .

The active suspension system has been investigated since 1930s, but for the bottle neck of complex and high cost for its hardware, it has been hard for a wide practical usage and it is only available on premium luxury vehicle . Semi-active (SA) suspension system was introduced in the early 1970s, it has been considered as good alternative between active and passive suspension system. The conceptual idea of SA suspension is to replace active force actuators with continually adjustable elements, which can vary or shift the rate of the energy dissipation in response to instantaneous condition of motion.

2. Related Work:

Kyongsu Yi et. al, (1992) [1], They present a semi-active suspension control algorithm to reduce dynamic tire forces including the development and application of observers for bilinear systems with unknown disturbances. The peak dynamic tire forces, which are greatly in excess of static tire forces, are highly dependent on the dynamic characteristics of vehicle suspensions. One way to reduce dynamic tire forces is to use advanced suspension systems such as semi-active suspensions.

Semi-active control laws to reduce dynamic tire forces are investigated and a bilinear observer structure for bilinear systems with unknown disturbances is formulated such that the estimation error is independent of the unknown external disturbances and the error dynamics are stable for bounded inputs. The motivation for the development of a disturbance decoupled bilinear observer comes from the state estimation problem in semi-active suspensions. An experimental study on the performance of a semi-active suspension to reduce the dynamic tire forces is made via a laboratory vehicle test rig. The semi-active suspension has been implemented by the use of a modulable damper, accelerometers and a

All Rights Reserved © 2020 IJRDASE

personal computer. Experimental studies using the laboratory test rig show that the performance of the semi-active suspension is close to that of the best passive suspension for all frequency ranges in the sense of minimizing the dynamic tire forces and that the dynamic tire force can be replaced by the estimated one. The dynamic tire forces for both passive and semi-active control test cases are compared to show the potential of a semi-active suspension to reduce the dynamic tire forces.
They found that a bilinear model of a semi-active suspension was formulated and it was shown via experimental data that a bilinear model does represent a semi-active suspension with sufficient accuracy. The performance of tire force feedback and the sprung mass velocity feedback cases are compared to determine which state is most important in dynamic tire force control. It has been shown that the performance of the tire force feedback with optimal passive damping case is similar to that of the full state feedback case in the dynamic tire force control. A bilinear observer whose estimation error is independent of the unknown disturbance has been developed and stability conditions for the observer were investigated. The necessary conditions for the measurements are relaxed compared to that of the disturbance decoupled bilinear observer that cancels the effect of the input and the disturbances in the observer internal model. The proposed bilinear observer was shown to be robust to parametric modelling errors [1].

Nader Jalili (2002) [2], Semi-active (SA) vibration-control systems are those which otherwise passively generated damping or spring forces are modulated according to a parameter tuning policy with only a small amount of control effort. SA units, as their name implies, fill the gap between purely passive and fully active vibration-control systems and offer the reliability of passive systems, yet maintain the versatility and adaptability of fully active devices. During recent years there has been considerable interest towards practical implementation of these systems for their low energy requirement and cost. This work briefly reviews the basic theoretical concepts for SA vibration-control design and implementation, and surveys recent developments and control techniques for these systems. Some related practical applications in vehicle suspensions are also presented.
The fundamental principles of SA suspension were formulated here. There are many important areas directly or indirectly related to the main theme of this work such as practical implementation of SA suspensions, nonlinear control schemes, actual hardware implementation, actuator bandwidth requirements, reliability and cost. Furthermore, in the process of designing a SA suspension, in practice, several critical criteria must be considered, which were not discussed here. These include weight, size, shape, centre of gravity, types of dynamic disturbances, allowable system response, ambient environment and service life.
SA suspensions provide vibration suppression solutions for tonal and broadband applications with small amount of control and relatively low cost. However, it is quite a design challenge by using conventional technologies to build a practical SA suspension under the constraints of weight, size and cost. Furthermore, the design of SA suspension involves many mechanical and electrical components that puts limit on the tuning range of the resonance frequency of the device [2].

Vadim i. utkin (1977) [3], Variable stmctme systems consist of a set of continuous subsystems together with suitable switching logic. Advantage properties from changing struetnres according to this switching logic. Design and analysis for this clafs of systems are surveyed in this work.

John Y. Hung et al., (1993) [4], A tutorial account of variable structure control with sliding mode is presented in this work. The purpose is to introduce in a concise manner the fundamental theory, main results, and practical applications of this powerful control system design approach. This approach is particularly attractive for the control of nonlinear systems. Prominent characteristics such as invariance, robustness, order reduction, and control chattering are discussed in detail. Methods for coping with chattering are presented. Both linear and nonlinear systems are considered. Future research areas are suggested and an extensive list of references is included.
Having travelled a long history of research and development, VSC is well established as a general control method. Its feasibility is increasingly recognized by control professionals, although there are still problems to be investigated. VSC is naturally attractive to control engineers because its basic concepts are rather easy to understand and has given satisfactory performance in many practical areas of industrial electronics. More importantly, VSC is applicable to many control systems where there are no other design methods are well-developed. Although contributions in the theoretical analysis and design of VSC systems will continue to improve, it is of major significance to also conduct experimental research for all kinds of industrial problem. The result of such studies will undoubtly enhance the confidence of practicing engineers considering the use of VSC [4].

J.J. Slotine et. al, (1982) [5], They developed a methodology of feedback control to achieve accurate tracking in a class of non-linear, time-varying systems in the presence of disturbances and parameter variations. The methodology uses in its idealized form piecewise continuous feedback control, resulting in the state trajectory 'sliding' along a time-varying sliding surface in the state space. This idealized control law achieves perfect tracking; however, non-idealities in its implementation result in the generation of an undesirable high frequency component in the state trajectory. To rectify this, we show how continuous control laws may be used to approximate the discontinuous

All Rights Reserved © 2020 IJRDASE

control law to obtain robust tracking to within a prescribed accuracy and decrease the extent of high frequency signal. The method is applied to the control of a two-link manipulator handling variable loads in a flexible manufacturing system environment.
Finally, they have used the currently important area of manipulator control as the trial area for our methodology. We are now in the process of implementing sliding mode control laws on different kinds of manipulators and simulating their performance. Given the inherent non-linearities involved in all but Cartesian manipulators, we feel that our methodology is particularly suited for this application.

E. M. Elbeheiry et. al, (1996) [6], A major purpose of any vehicle suspension system is to isolate the body from roadway unevenness disturbances. On rough roads or at very high speeds on smoother roads suspension detection may become large enough to cause frequent bottoming thus causing a severe degradation of isolation. Variable parameter suspensions are optimized to use the available suspension detection to provide maximum isolation. Broadband stochastic roadway inputs at several intensity levels are applied to a quarter car model and the suspension parameters are optimized to the best possible isolation under the equality constraint that the rms suspension detection is a constant value in every case. From these results improvements can be designed on the basis of measured suspension travel signals. Five types of suspension systems are investigated. These systems are called the fully active the limited active\ the optimal passive the actively damped and the variable damper systems. Comparisons are made among these systems in terms of rms response frequency domain predictions and eigen frequency behavior as functions of disturbance intensity. The results show that such an adaptation philosophy would work well for moderate and high roadway intensities. For very smooth roads\ forcing the suspension system to provide a specific travel does not produce a useful result\ because at low disturbance intensities the normal tire force variation becomes unnecessarily large as the system is forced to maintain constant rms suspension detection The fully active suspension system provides much better body isolation than the other types with or without equality constraint Finally the fully active system requires minimum suspension control force to maintain constant suspension travel compared with the other types of suspension considered.
A policy for adapting suspension systems based on suspension travel is suggested. The results are successful in reducing frequent bottoming at moderate and high road intensities but less so on relatively smooth roads. The fully active system requires the lowest amount of control force to maintain constant suspension travel. A policy for active suspension systems with constrained suspension travel for various road intensities requires approximate linear and nonlinear adjustment of the optimum feedback gains as a function of roadway disturbance intensity. Linear adaptation of damping gain for variable damper systems is suficient to attain their performance potential[Suspensions having only a variable passive damper behave almost the same as passive systems having a variable spring and damper except that the latter provides much better isolation near body resonance for moderate road roughness [6].

Yanqing LIU et. al. [7], Semi-active systems with variable stiffness and damping have demonstrated excellent performance. However, conventional devices for controlling variable stiffness are complicated and difficult to implement in most applications. To address this issue, a new configuration using two controllable dampers and two constant springs is proposed. This work presents theoretical and experimental analyses of the proposed system. A Voigt element and a spring in series are used to control the system stiffness. The Voigt element is comprised of a controllable damper and a constant spring. The equivalent stiffness of the whole system is changed by controlling the damper in the Voigt element, and the second damper which is parallel with the other elements provides variable damping for the system. The proposed system is experimentally implemented using two magnetorheological fluid dampers for the controllable dampers. Eight different control schemes involving soft suspension, stiff suspensions with low and high damping, damping on-off (soft and stiff), stiffness on-off (low and high), and damping and stiffness on-off control are explored. The time and frequency responses of the system to sinusoidal, impulse and random excitations show that variable stiffness and damping control can be realized by the proposed system. The system with damping and stiffness on-off control provides excellent vibration isolation for a broad range of excitations.
A new variable stiffness and damping system configuration using two controllable dampers was proposed. Since the stiffness is controlled by changing the damping coefficient, this system is very simple and easy to apply in practical systems. The system is experimentally investigated using the MR damper that the damping can be changed easily. Based on the experimental and calculation results, the proposed control system has good performances for the vibration isolation, especially, it has the smallest displacement responses. The acceleration is a little larger than those of the soft spring systems, however, the soft spring systems has larger compliance and they are not applicable for the real systems which has not only the base excitation but also the force excitation [7].

Rajeswari Kothandaraman et. al (2012) [8], In this work, Particle Swarm Optimization (PSO) technique is applied to tune the Adaptive Neuro Fuzzy Controller (ANFIS) for vehicle suspension system. LQR controller is used to obtain the training data set for the vehicle suspension system. Subtractive clustering technique is used to formulate ANFIS which approximates the actuator output force as a function

All Rights Reserved © 2020 IJRDASE

of system states. PSO algorithm search for optimal radii for subtractive clustering based ANFIS. Training is done off line and the cost function is based on the minimization of the error between actual and approximated output. Simulation results show that the PSO-ANFIS based vehicle suspension system exhibits an improved ride comfort and good road holding ability.

In this work, particle swarm optimization technique has been used to tune the ANFIS controller through subtractive clustering for the quarter car model based active suspension system. The cost function associated with PSO algorithm is formulated as square of error between actual and approximated control signals. Trained ANFIS simplified the control of active suspension system. ANFIS requires low computational complexity and it was found to be more convenient to obtain the desired relationship between inputs and output. Simulation results demonstrate the effectiveness of the proposed controller. ANFIS based active suspension provides higher ride comfort and road handling qualities when compared to existing passive and ANFIS without PSO [8].

Nurkan Yagiz et. al (2008) [9], In this work, the active suspension control of a vehicle model that has five degrees of freedom with a passenger seat using a fuzzy logic controller is studied. Three cases are taken into account as different control applications. In the first case, the vehicle model having passive suspensions with an active passenger seat is controlled. In the second case, active suspensions with passive passenger seat combination are controlled. In the third case, both the passenger seat and suspensions have active controllers. Vibrations of the passenger seat in the three cases due to road bump input are simulated. At the end of the study, the results are compared in order to select the combination that supplies the best ride comfort.

In this work, five degrees of freedom vehicle model having a passenger seat has been controlled using three different approaches. These are, at first, the vehicle model with passenger seat having a controller under it; secondly, with passive passenger seat but suspensions having controllers parallel to them; thirdly, with passenger seat having a controller under it together with suspensions having controllers parallel to them, respectively. The second case seems to be better than the first one while the third case is being the best. The results have been proved that, among three control strategies considered, using controllers under the vehicle body and passenger seat at the same time would provide the best ride comfort. Since adding a controller under the passenger seat together with the active suspensions improves ride comfort the most and does not cost much, the third control application is to be preferred [9].

E. E. El-kholy et. al [10], This work present fuzzy logic control (FLC) based speed control system for a DC Motor drive through the use of Genetic optimization. The control system design and implementation procedures of DC motor drive using Digital Signal Processor are described. Results of simulation and experimental on the real control system demonstrated that the proposed FLC is able to overcome the disadvantage of use PI controller. Also, the results obtained have shown the feasibility and effectiveness of the control system.

In this work, they realized the controller for a DC motor, which is demanded increasingly using the fuzzy logic. We present fuzzy reasoning algorithm to control DC motor in order to improve the PI controller, which is hard to get optimum control under the unstable driving situation or different condition of load and speed. The simulation and experimental study clearly indicates the superior performance of fuzzy control, because it is inherently adaptive in nature [10].

Jiangtao Cao et. al., (2008) [11], This work review computational-intelligence involved approaches in active vehicle suspension control systems with a focus on the problems raised in practical implementations by their nonlinear and uncertain properties. After a brief introduction on active suspension models, the work explores the state of the art in fuzzy inference systems, neural networks, genetic algorithms, and their combination for suspension control issues. Discussions and comments are provided based on the reviewed simulation and experimental results. The work is concluded with remarks and future directions.

Computational-intelligence-based adaptive control approaches are required due to the real-time, nonlinear, and uncertain nature properties of active suspension systems. This work provided an account of the state of the art of adaptive ASCSs with intelligent methodologies. Their advantages and disadvantages are concluded based on theoretical analysis, analyzing simulations, and the experimental results of the reviewed systems. In summary, the fuzzy control systems with learning and adaptive capability can be used to solve most modeling problems and the uncertain disturbance of active suspension systems. However, the control stability analysis is also a bottleneck for the application of fuzzy control systems. A sliding-mode controller with an FL system has been studied to integrate the advantages of transferring human expert knowledge and stability verification. However, these designs are always complex, and the tuning parameters are not easily operated by the engineers. From the point of adaptive ability, the NN and GA also have shown many advantages in suspension systems by simulations and applications. In addition, the combination of these methods hopes to bring better performance. Simultaneously, these hybrid systems have shown poor interpreting ability and are difficult to evaluate in the same test case [11].

M. Kondalu et. al. (2012) [12], Fuzzy logic based control systems provide a simple and efficient method to control highly complex and imprecise systems. However, the lack

All Rights Reserved © 2020 IJRDASE

of a simple hardware design that is capable of modifying the fuzzy controller's parameters to adapt for any changes in the operation environment, or behaviour of the plant system limits the applicability of fuzzy based control systems in the automotive and industrial environments.
Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary or are initially uncertain. Despite the lack of a formal definition, an adaptive controller has a distinct architecture, consisting of two loops control loop and a parameter adjustment loop.
In this project automotive suspension system parameters are controlled by adaptive fuzzy logic controller and for which simulation results are obtained in MATLAB environment.
In this work, adaptive fuzzy logic controller was presented. The main characteristic of this architecture is the fuzzy controller's ability to accept new rule base, and membership functions during runtime without causing any undesirable behaviour to the plant. The proposed fuzzy controller was used to enhance the performance of a vehicle suspension system, by generating the damping coefficient required by the variable damper in the semi-active suspension systems. Simulation results demonstrated the controller's ability to stabilize a vehicles suspension system. During the course of the simulations, the controller's membership functions, and rule base were modified twice by the optimization block. Simulations demonstrated the controller's ability to adopt the new parameters in the control process without negatively affecting the response of the system [12].

Yi Chen, (2009) [13], A skyhook surface sliding mode control method was proposed and applied to the control on the semi-active vehicle suspension system for its ride comfort enhancement. A two degree of freedom dynamic model of a vehicle semi-active suspension system was given, which focused on the passenger's ride comfort performance. A simulation with the given initial conditions has been devised in MATLAB/SIMULINK. The simulation results were showing that there was an enhanced level of ride comfort for the vehicle semi-active sus-pension system with the skyhook surface sliding mode controller.

3. Conclusion:
In this work additional 5x5 fuzzy rule are considered to enhance the standard fuzzy inference system based suspension control mechanism. It has been observed that by using this novel fuzzy logic controlled system in hybridization with classical sliding mode non linear control theory body aberration occurred due to road vibrations are significantly reduced. The power spectrum of the body acceleration in frequency domain is also generated. It also justifies that the resonant peak by adder fuzzy rule hybrid suspension control mechanism gets reduced that can improves the ride comfort.

References:

[1] Kyongsu Yi et. al., "Dynamic Tire Force Control By Semi-Active Suspensions", 1992 ASME Winter Annual Meeting November 1992 Anaheim, CA.

[2] Nader Jalili, "A Comparative Study and Analysis of Semi-Active Vibration-Control Systems", Journal of Vibration and Acoustics Copyright © 2002 by ASME

[3] Vadim i. utkin, "Variable Structure Systems with Sliding Modes", IEEE TRANSACTIONS ON AUTOMATIC NCOO.N TR AOCL-,2 V2,O L. 2, APRIL 1977

[4] John Y. Hung, "Variable Structure Control: A Survey", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 40, NO. 1, FEBRUARY 1993.

[5] J.J. Slotine et. al, "Tracking Control Of Non-Linear Systems Using Sliding Surfaces With Application To Robot Manipulators" December 1982 LIDS-P-1264.

[6] E. M. Elbeheiry et. al, "Optimal Control Of Vehicle Random Vibration With Constrained Suspension Deflection", Journal of Sound and Vibration "0885# 078"4#\ 436453.

[7] Yanqing LIU et.al, "Semi-active vibration isolation system with variable stiffness and damping control",

[8] Rajeswari Kothandaraman et. al., "PSO tuned Adaptive Neuro-fuzzy Controller for Vehicle Suspension Systems", journal of advances in information technology, vol. 3, no. 1, february 2012.

[9] Nurkan Yagiz et. al., "Different control applications on a vehicle using fuzzy logic control", Sadhana Vol. 33, Part 1, February 2008, pp. 15–25.

[10] E. E. El-kholy et. al., "Speed Control Based on Adaptive Fuzzy Logic Controller For AC-DC Converter Fed DC Motor Drives"

[11] Jiangtao Cao et. al., "State of the Art in Vehicle Active Suspension Adaptive Control Systems Based on Intelligent Methodologies" IEEE transactions on intelligent transportation systems, vol. 9, no. 3, september 2008

[12] M. Kondalu et. al., "Vehicle Suspension System Control by using Adaptive Fuzzy Controller" International Journal of Engineering and Technology Volume 2 No. 3, March, 2012

[13] Yi Chen, "Skyhook Surface Sliding Mode Control on Semi-Active Vehicle Suspension System for Ride Comfort Enhancement" Engineering, 2009, 1, 1-54

All Rights Reserved © 2020 IJRDASE