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A Review on Controlling Methods for Semi-Active Suspension Systems

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***Abstract:** In recent years the need of vehicle safety and ride comfort has led to develop effective modeling and control methods of suspension system. There are many methods already found to develop and control this kind of suspension systems. Mainly there are three types of suspension systems, Active, Semi-Active and Passive suspensions. This research paper presents a comprehensive review of controlling methods employed in semi-active suspension systems, a critical component in modern vehicle dynamics. Out of these three, semi-active suspension has the ability to adapt with the technical changes in the system model. In this paper some of the control methods for the semi-active suspension system have been discussed and a quick review is done on their way of operation. Moreover, the paper addresses recent advancements in semi-active suspension control, such as the integration of machine learning and optimization techniques.*

***Keywords:** Vehicle Dynamics, Semi-active suspension, Controlling methods, Vehicle Stability, Ride Comfort, Optimization techniques.*

I. INTRODUCTION

There are different kind of performance levels in terms of road handling, vibration isolation, and ride comfort that should be ensured by the suspension system of the vehicle. On the basis of external power source input, the vehicle suspensions can be classified mainly into three types:

A. Semi-active, Active and Passive

The Semi-active suspensions have been the main focus of research because of their better performance than passive suspension and lower energy consumption than active ones. [1]

Main components of this kind of semi-active suspension system consist of the spring and the dampers. By reducing the stiffness and damping of this suspension system can help in shock absorption and vibration reduction improving the vehicle stability and ride comfort of passengers. [2]

These semi-active suspensions have become popular in automotive field because of their cost-effective solutions that can be utilized to significantly to increase driving comfort. The initial technology for semi-active suspensions was the so-called linear adaptive configuration. In recent years various approaches and methods have been proposed to model and control these kinds of systems, such as-optimal control (Poussot-Vassal et al., 2006), MPC (Canale et al., 2006), LPV (Poussot-Vassal et al., 2008).[4] Some of which we have tried to review here.

A. Multi-Modes Control of Semi-active Suspension by CVD

As per author, G. BEL HAJ FREG et.al (2020) a continuously variable damper (CVD) is used for design and analysis of a multi-mode semi-active suspension for a quarter car. Here for the quarter car model three modes of suspension have been developed and a method of modelling for the CVD is presented. The damper units here used is composed of passive metallic spring which has associated with the actuators to provide high vehicle regulation.

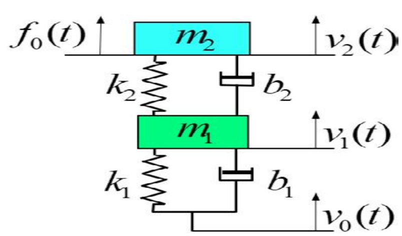

Fig -1: Quarter-car vehicle suspension model [1]

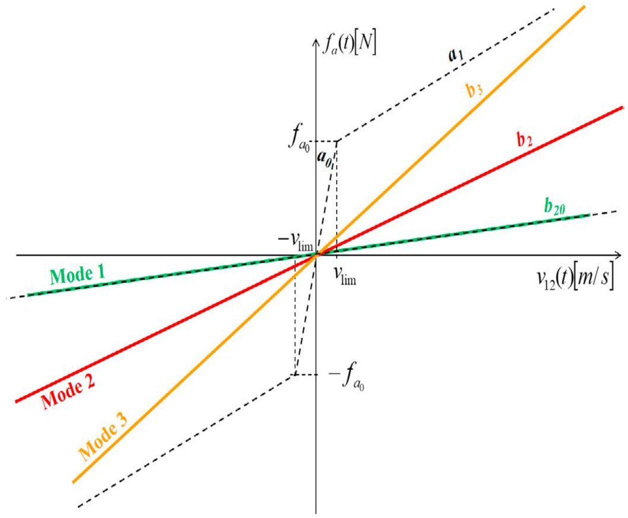

Fig-2: The variation ranges of the suspension efforts for the three suspension modes.

As the investigated damper's damping adjustment is more effective so it can achieve various suspension modes by adjusting the actuation force. Both ride comfort and driving safety can be achieved by applying a suitable control strategy to the damper by minimizing the quadratic gap between the control actuation force for each mode and a control target. The CRONE-SkyHook approach is used to synthesize the control target. For this method effectiveness is confirmed using a real measured road profile and a speed bump profile.

B. Vibration Control of Semi-active Suspension by Neural Network

The Author, Kaoru Sato et.al suggests an approach to control semi-active suspension which takes into account the forward road surface geometry. Using an MLD (Mixed Logical Dynamical) model which represents a vehicle model with a semi-active suspension, information about potential disturbances for road ahead can be obtained prior to the vehicle experiencing them.
Here they formulated MIQP (Mixed Integer Quadratic Programming) in the same manner as the standard optimal control problem without future disturbances. By using MLD preview control neural network approximation the control input signal within the control cycle period can be calculated, while maintaining the similar control performance of the MLD preview control.

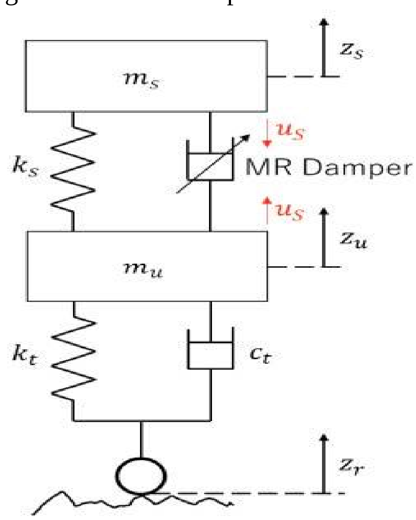

Fig -2: A quarter car model with MR damper as semi-active suspension.

This method performs better than all other options and cannot be used to control an automobile on a standard computer. The author here assumed that the MR dampers can achieve the desired damping and stiffness in a reasonable amount of time. On the other hand, some variable dampers needed a non-negligible amount of time to reach the desired damping characteristics and stiffness.

C. Cloud Based Adaptive Control of Semi-active Suspension

Here the author, Hakan Basargan et.al uses cloud computing to implement adaptive suspension control using historical road data collected in the cloud database, based on integrated approach of vehicle-to-cloud-to-vehicle. A novel technique is developed to get an adaptive semi-active suspension control method using various scheduling parameter design approaches based on cloud application. A scheduling parameter assure balance between vehicle stability and driving comfort whose architecture is based on Linear Parameter-Varying Framework.

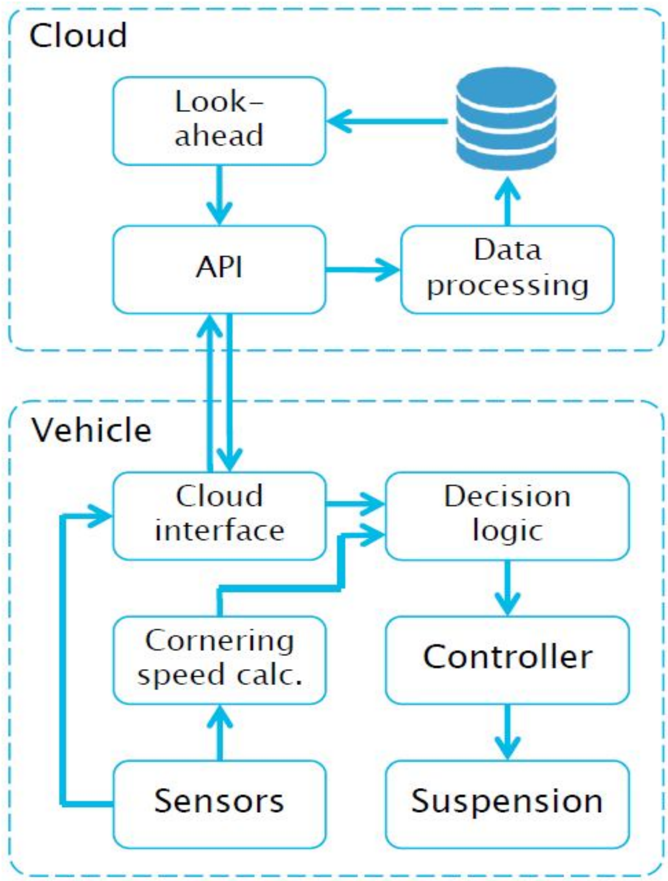

Fig-3: System Architecture[5]

Fig-4: Vehicle to cloud to vehicle architecture

A new concept of cloud assistance to adjust the controller's performance based on upcoming road conditions to improve driving and safety performances is developed. In this method gathering data, dynamic vehicle signals and storing is done on road irregularities and velocity in the cloud database based on vehicles previously travelled route. Then the cloud computes the corresponding scheduling variables for every unique road irregularity and velocity. The intensity of the factors affecting these variables like vehicle's speed, kind and intensity of road irregularities is reduced and the driving comfort is also increased along with vehicle stability. These improved changes are observed through the simulation done.

D. An LMI Based Approach

Here the author, Ruben Begnis et.al has used magnetorheological (MR) fluids to model and control semi-active suspension. Here a saturation-based model of the underlying nonlinear phenomenon is presented in order to integrate the MR suspension for the quarter car model's parameters as similar to those of an of an SUV.A constant input maintained throughout the simulation and the application of the Skyhook controller are modified from its usual application in electrohydraulic suspensions to evaluate the comfort of passengers by demonstrating simulation results. Then they suggested the LMI-based control schemes to apply sector conditions and get an approximated model for saturation nonlinearities.

Differential equations describing quarter car model as follows:

$$\begin{cases} m_s\ddot{z}_s = -k\tilde{z} - f_d(\tilde{z}) \\ m_u\ddot{z}_u = -k_t(z_u - z_r) + k\tilde{z} + f_d(\dot{\tilde{z}}), \end{cases}$$

Here they have discussed the control synthesis for a semi-active suspension based on magnetic resonance effects. Firstly, approximation model based on a semi-definite program was expressed in terms of linear matrix inequalities for efficient tuning was presented which enables the optimal tuning of a state feedback gain. Next, they showed that, in comparison to the passive scenario the classical Skyhook control technique does not yield appreciable improvements. Lastly, the efficiency of the recommended method was verified by the simulation results.

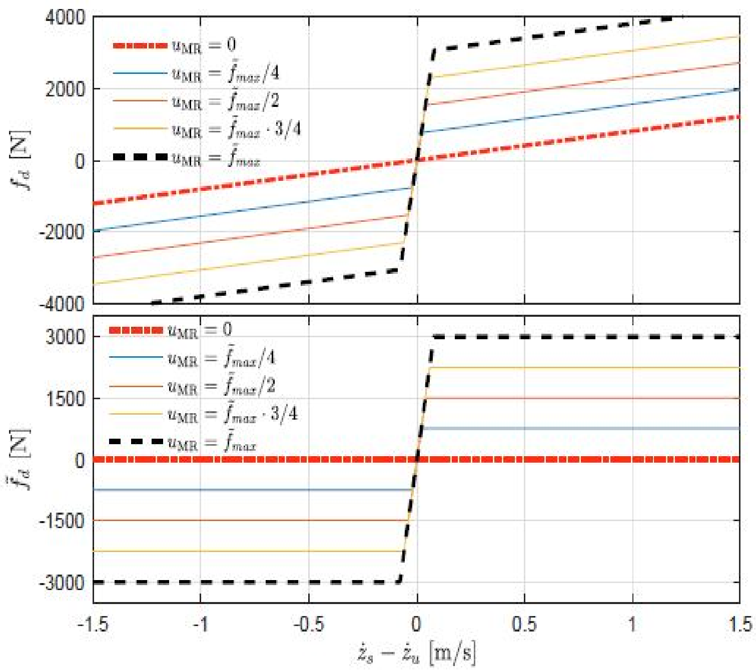

Fig-4: Typical force-speed curve associated to a MR sus-pension (upper plot) and the corresponding nonlinearity (lower plot).

E. Hydro-pneumatic Inerter-based Suspension System with MPC Control Strategy

As per Lin Yang, et. Al, a non-linear model including SAHPISS was built in AMESim, which is a time continuous block simulation model.

To establish a nonlinear mathematical model of the HPISS, the following assumptions are listed:

1) The fluid properties (density, bulk modulus, etc.) are constant.
2) The hydraulic control valve is not saturated.
3) The friction force can be modeled as a part of the damping force.

The SAHPISS model is a two DOF system along with a model predictive control

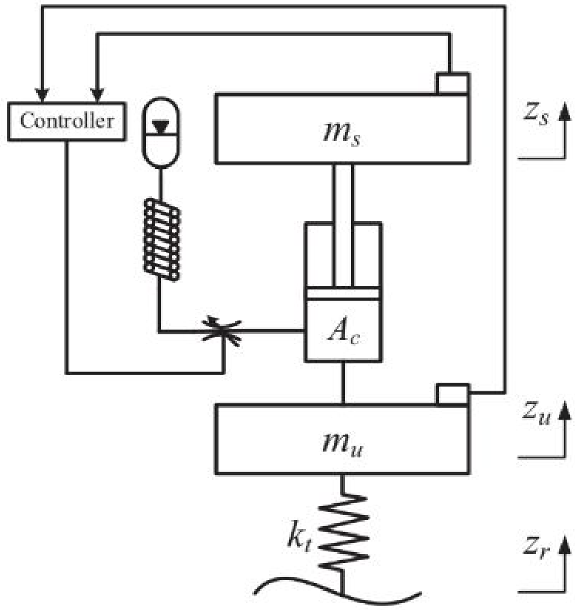

Fig-4: Dynamic model of SAHPISS[6]

The SAHPISS is tested by the bench test to further validate the accuracy of the results. The body acceleration, the dynamic tire load and the suspension working space of SAHPISS are significantly lower than that of HPSS. The simulation results show that the body acceleration, the tire load and the suspension working space of SAHPISS are optimized by 18.3%, 15.9% and 32.5%, respectively with HPSS.

II. CONCLUSIONS

When the effective driving comfort and vehicle handling are necessary then the semi-active suspension system proves to be more efficient. As it can adopt certain modifications which will help it to achieve the high quality of vehicle stability and road comfort. By simply controlling the actuation force the damping can be adjusted efficiently.[1]

The MR dampers can achieve required stiffness and damping within the short interval of time than the other ways.[2]

By computing the cloud database of upcoming road-conditions the adaptive semi-active suspension systems can improve driving and confirm the safety of passengers.[3]

III. FUTURE SCOPE

Future work can be done in autonomous vehicles on their road behavior and safety.[1]

A non-negligible amount of time may be needed for certain variable dampers to reach the desired stiffness and damping properties. So future work with the actuator delay can be done to modify MLD preview control to fit these response-delayed, semi-active devices.[2]

The ability of sensors sensing the road irregularities can be improved in future to increase accuracy of cloud computing technique. [3]

Training ANN controllers can also be done to study its effect on Semi-Active suspensions with MR dampers.[7]

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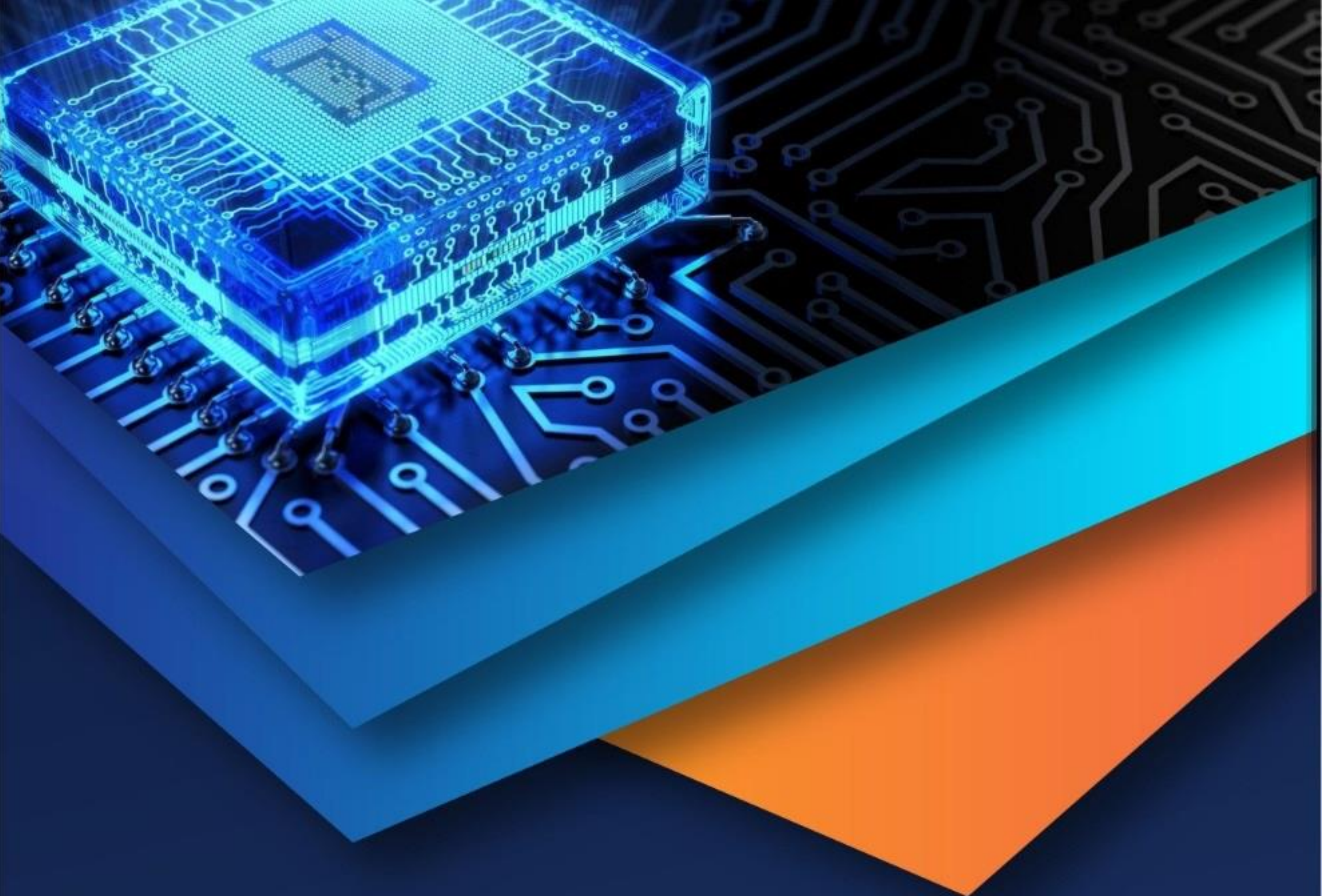

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