OPTIMIZATION IN SLIDING MODE CONTROL MECHANISM FOR REDUCING VIBRATIONS IN THE QUARTER VEHICLE USING FUZZY LOGIC CONTROLLER

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ABSTRACT

The suspension maintains a managed damping traction force between the tyres and the pavement to support and isolate the vehicle body and cargo from road vibrations generated by surface roughness. In today's high-end vehicles, the semi-active suspension is accurate and dependable, increasing ride comfort while decreasing fuel consumption. To improve the ride quality of a semi-active car suspension, we have created a hybrid system that blends fuzzy logic control with the skyhook hypothesis. The 2-degrees-of-freedom (DOF) dynamic model of a car with semi-active suspension is simulated in Matlab/Simulink, and the ride comfort performance is analyzed.

Keywords: *Fuzzy inference system, vibration control, sliding surface, error control.*

I. INTRODUCTION

The original purpose of the one-fourth car model was to test the effectiveness of active suspension; its progeny, skyhook damping and rapid load levelling are now being refined for real-world, mass-production uses. In 1974, Karnopp et al. presented a method for controlling Skyhooks that is now widely regarded as one of the most effective methods of its kind. The driver controls the "skyhook" damper to connect the vehicle's spring mass to the inert atmosphere above. This damper has the potential to give the controllable force of a skyhook, reducing the vertical vibrations caused by traffic disruptions. A single inertia damper between the sprung mass and inertia frame in the prototype. Both passive and active systems may benefit from Skyhook's control. The damping force is passively modulated by the skyhook control law to mimic the force generated by a damper fixed to the sky as an inertial reference.

By adjusting the Skyhook, it is possible to significantly dampen the sprung mass's resonant peak and improve the ride's smoothness. This idea is used to give a gentle switching control rule for switching the primary sliding surface, which reduces the frequency with which sliding chattering occurs. This means the Skyhook SMC might eventually have premium-grade switches.

By the 1960s, Emelyanov had published his groundbreaking work on variable structure control (VSC) with sliding mode control, which he had first developed in the early 1950s. "In the years that followed, several scholars proposed novel approaches. Controlling complicated, high-order, nonlinear dynamical systems using sliding mode control is a reliable and effective strategy (SMC).

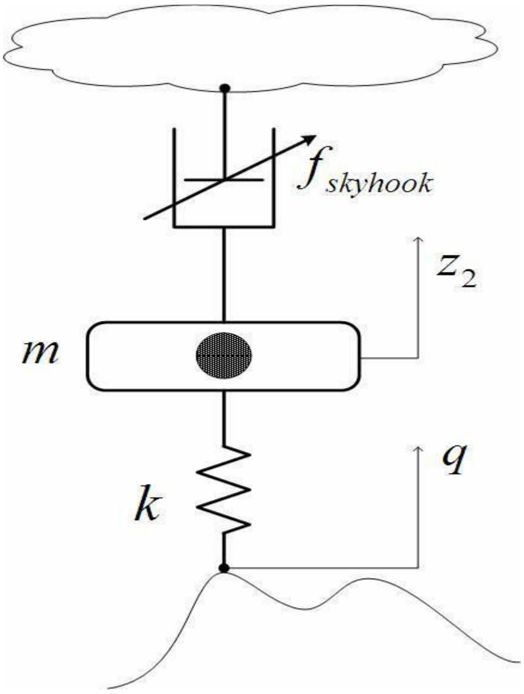

Fig 1: the optimal Skyhook control system

Sliding mode control's main benefits lie in its capacity to decouple system motion into discrete, lower-dimensional partial components and its low sensitivity to changes in a system's parameters across various uncertainty circumstances." A significant shortcoming of conventional SMC is its susceptibility to chattering, a problem common in control systems. The field of SMC has exploded in recent years, with several publications exploring ways to improve traditional SMC for more efficient operation and less noise.

Our goal is to create a new kind of control system that combines the most beneficial aspects of two existing types of control, namely skyhook surface sliding mode control and fuzzy logic control. These parts will be incorporated into a semi-active suspension system to improve ride quality. A two-degree-of-freedom semi-active suspension system is modelled dynamically for passenger convenience. The simulation software MATLAB/SIMULINK will be used to create this.

II. RELATED WORK

Systems that are exceedingly complicated and imprecise. M. Kendall et al. (2012) [5] made it possible for it to be readily and efficiently managed. Because of the difficulty in adjusting the settings of a fuzzy controller to account for changes in the operating environment or the behaviour of a plant system, fuzzy-based control systems are currently only used in the transportation and manufacturing industries. A controller engages in adaptive control to adapt its control approach to a controlled system with uncertain or changing characteristics. There is no good way to describe adaptive controllers, but their distinctive architecture—which includes a control loop and a parameter adjustment loop—makes them easy to spot.

For instance, Particle Swarm Optimization (PSO) was proposed by Kothandaraman Rajeswari et al. (2012) [4] for fine-tuning the Adaptive Neuro-Fuzzy Suspension (ANFS) Controller. To learn how to adjust the vehicle's suspension, the LQR controller is utilized to gather training data. To formulate ANFIS, we employ subtractive clustering to approximate the model of actuator output force as a function of system states. The PSO algorithm uses a technique similar to ANFIS to find the best possible radii for clustering. In a separate training set from production, the cost function is optimized to reduce the gap between actual and predicted output. “Simulation findings demonstrate that the vehicle's suspension system, based on PSO-ANFIS, enhances road holding and ride comfort.”

The semi-active systems whose stiffness and damping vary have been demonstrated to operate very well by LIU Yanqing et al. [3]. However, conventional systems for controlling variations in stiffness are challenging to implement in the great majority of contexts due to their complexity. We propose a novel arrangement that includes two constant springs and two dampers. We explore the proposed system theoretically and experimentally in this study. The system's stiffness is controlled by a series-connected spring and Voigt element. A constant spring and an adjustable damper make up the Voigt element. Changing the damper in the Voigt element changes the system's equivalent stiffness, and the second damper, perpendicular to the others, allows for damping to be changed. The experimental implementation of the proposed system makes use of two dampers loaded with magneto-rheological fluid in their role as adjustable dampers. In total, eight various forms of control are investigated, such as on/off damping for soft/stiff suspensions, low/high damping, stiffness control, and on/off damping/stiffness control. Time-domain and frequency-domain responses to sinusoidal, random, and impulsive excitations demonstrate the proposed system's capacity to control dynamic stiffness and damping. Superior vibration isolation is provided by a wide range of excitations thanks to the system's on/off damping and stiffness management.

To achieve precise tracking in a group of nonlinear, time-varying systems despite disturbances and parameter variations, Slack et al. (1982) [2] suggested a feedback control method. By using piecewise continuous feedback control, the idealized form of the method "slides" the state trajectory over the state space along a dynamic sliding surface. “However, due to implementation defects, this idealized control law achieves perfect tracking at the expense of an undesirable high-frequency component in the state trajectory.” We illustrate how a continuous control law, approximating the discontinuous control law, may reduce the effect of the high-frequency signal and allow robust tracking with the desired precision. “The technology is implemented to control a two-link manipulator in a versatile manufacturing setup that can handle different loads.”

Using a sliding mode, John Y. Hung et al. (1993) [1] describe regulating a system's variable structure. A concise overview of the theory, fundamental discoveries, and practical uses of this powerful approach to designing control systems will be provided. The potential for this approach to be applied in applications where nonlinear systems need to be controlled successfully is particularly exciting. In this article, we examine the role of crucial qualities like invariance, resilience, order reduction, and control chattering in the field. Methods for dealing with chitchat are discussed. We take into account both linear and nonlinear systems. There is an extensive list of resources and potential areas of research.

III. METHODOLOGY

Fuzzy logic control, which uses heuristic information to ease the building of nonlinear controllers, is a feasible solution for a wide variety of complicated control applications. The "person in the loop" controller's experience is the basis for the fuzzy logic controller. Provides a human experience that is grounded on the representation and application of human beliefs about peak performance management.

In Figure, we can see the SA suspension system's 2-DOF implementation on the FLC. Next, the experts' knowledge is characterized by an "If-Then" rule set. Fig. A set of FLC rules with a 2-in-1-out structure, sometimes known as 2. Language description criteria in FLC are based on conceptual competency gathered from everyday human experience. Comfortable riding is ensured by the 2-DOF SA suspension system, which relies on a rule base developed from previous work on semi-active damping force adjustment in response to variations in body acceleration. In order of importance, the following are the fundamental rules of language: Firstly, because the SA damping force rises with the body's acceleration, and secondly, the inverse is true when the acceleration of the body decreases.

Figure 1 is a rule-based 3D cloud map showing the relationship between one output (U) of a semi-active control force and two inputs (E) of error and the variation in error (EC). See Table 1 for the complete 2-in-1-out FLC rule base to translate the input data from the semi-active suspension body's acceleration to the output control force.

The variables' actual world locations may be "mapped" onto the fuzzy space by first decomposing the inputs into fuzzy sets. By fuzzifying a system, its inputs and outputs may be stated in everyday language, making applying the rules needed to describe its complex behaviour easier. The Fuzzy Logic Controller (FLC) of a two-degrees-of-freedom (DOF) SA suspension system needs seven components: NL, NM, NS, ZE, PS, PM, and PL in the fuzzy sets for the error inputs (Error(E) and Error(EC)) and the Fuzzy Logic (FL) output. De-fuzzification is the opposite of fuzzification, and it entails remapping the variables from the fuzzy space to the actual space.

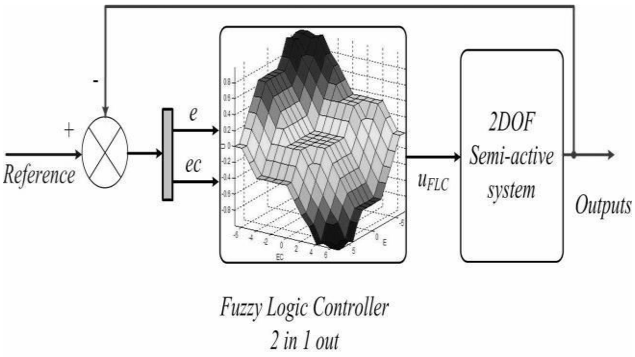

Fig 2: Sequence chart for two-in-one-out fuzzy logic control.

One way of looking at a membership function (MF) is as an enhanced version of the indicator function often used with classical sets. This parameterization defines the function by assigning a value between 0 and 1 to each point in the input space. As can be seen in Figure 3, the 2-DOF SA suspension system uses a triangular MF since the MFs for E, EC, and U all use the same element range. This fuzzy set is used to make sense of E and EC values in addition to membership degrees.

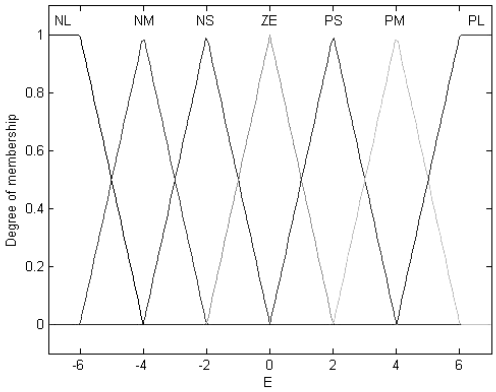

Fig 3. The FLC controller can use a triangular membership function more effectively and efficiently.

Unstretched mass force balance model equation: Through this model, we can relate observations of road disruptions to the balance of unsprung masses and forces (1). The following values and constants are used in this equation: 1). The model's attention is drawn to the unsprung mass force condition shown in Fig. 4.

In this image, you can see the input blocks addressing the reenactment borders and the power condition of the 2-DOF SAS framework.

An example of an unmasked data input block is shown in Figure 5. Input blocks receive the variables m1, m2, k1, k2, co, fr, and g. A 7x1 multiple block processes each constant input since mux output is bound in the simulation. We consider the mass m1 and the displacements z1 and z2 and use a de-multiplexer to extract the individual signals from the multiplexed output of the product block. Since z1" reflects the acceleration of m1 owing to body inertia and load disturbance, Summer bock's model yields m1z1" as the force acting on m1's unsprung mass. “In order to get the product, we utilize the product block and multiply the total of k1(z1-q), k2(z1-z2), c0(z1'-z2'), -m1g, and fr (=c2(z2'-z1')) by 1/m1. Product block liberates z1 in this way.”

Table 1: 2-DOF SA suspension parameters

m1	Un-sprung mass, kg	36
m2	Sprung mass	240
c2	Suspension damping coefficient, Ns/m	1400
k1	Tire stiffness coefficient, N/m	160000
k2	Suspension stiffness coefficient, N/m	16000
G	Gravity acceleration, m/s^2	9.81
Ke	FLC scaling gain for e	-1
Kec	FLC scaling gain for ec	-10
Ku	FLC scaling gains for you	21
Co	SkyhookSMC damping coefficient	-5000
Δ	The thickness of the sliding surface	28.1569
Λ	The slope of the sliding surface	10.6341
No	Reference space frequency,m^-1	0.1
P(no)	Road roughness coefficient, m^3/cycle	250x10^-6
Vo	Velocity, km/h	72

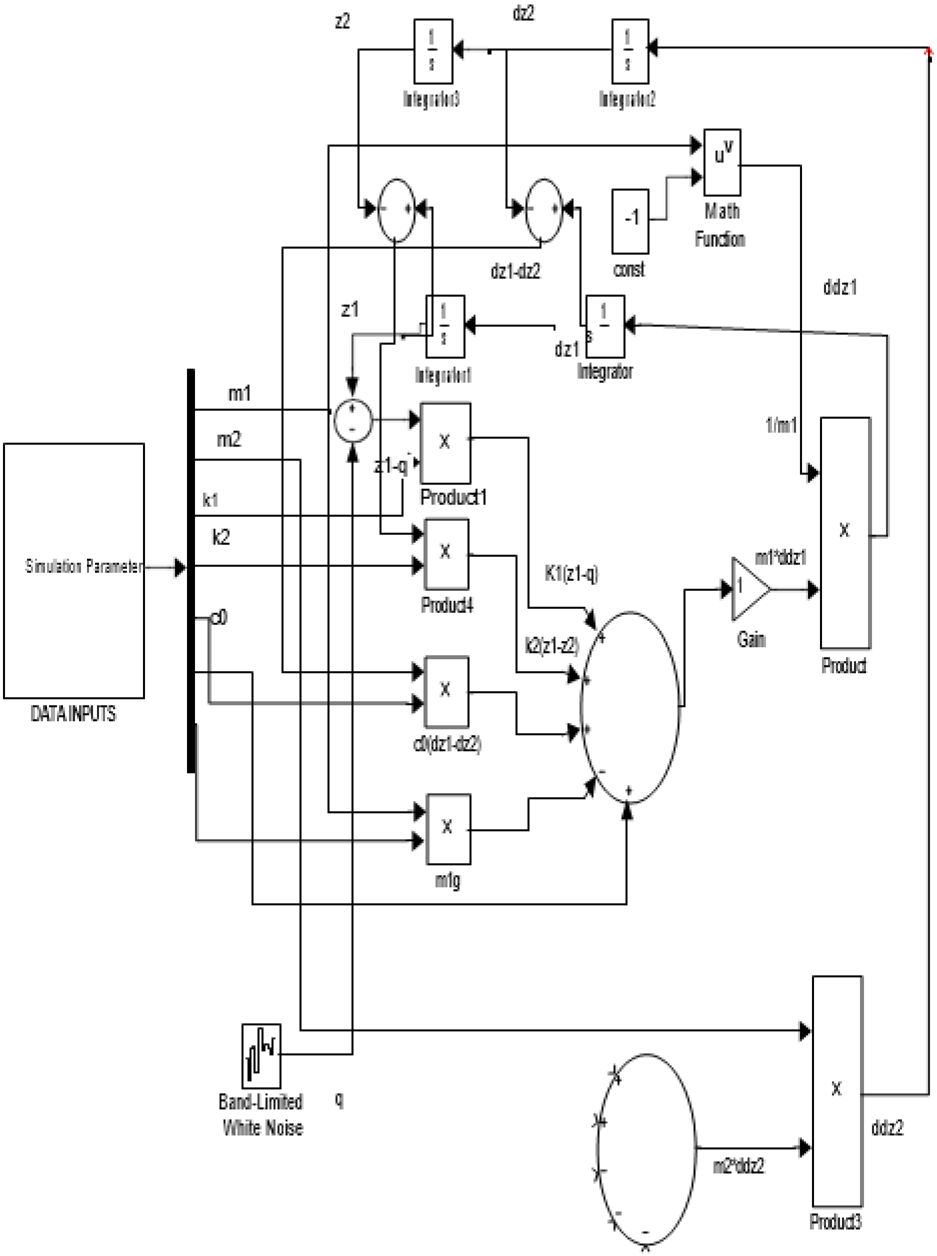

Fig 5 The Un-sprung Mass as a Force-Balancing Model Equation

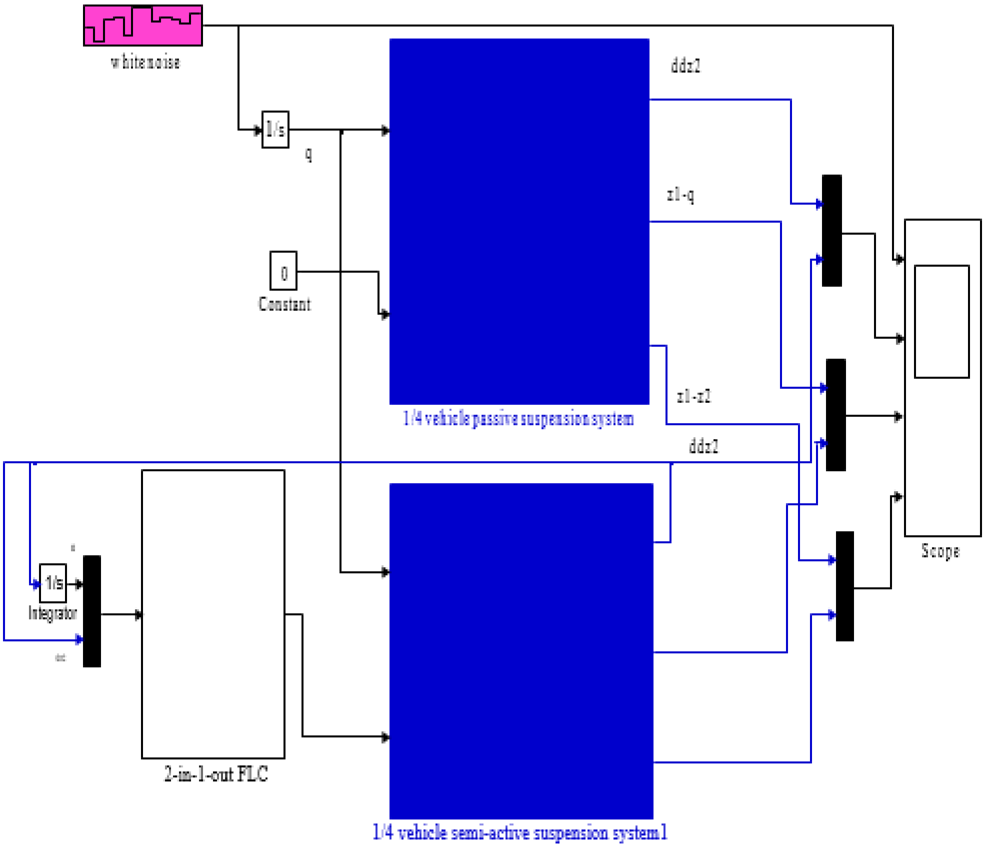

Fig 6 (a): Suspension system with Fuzzy Control Modeled in Simulink

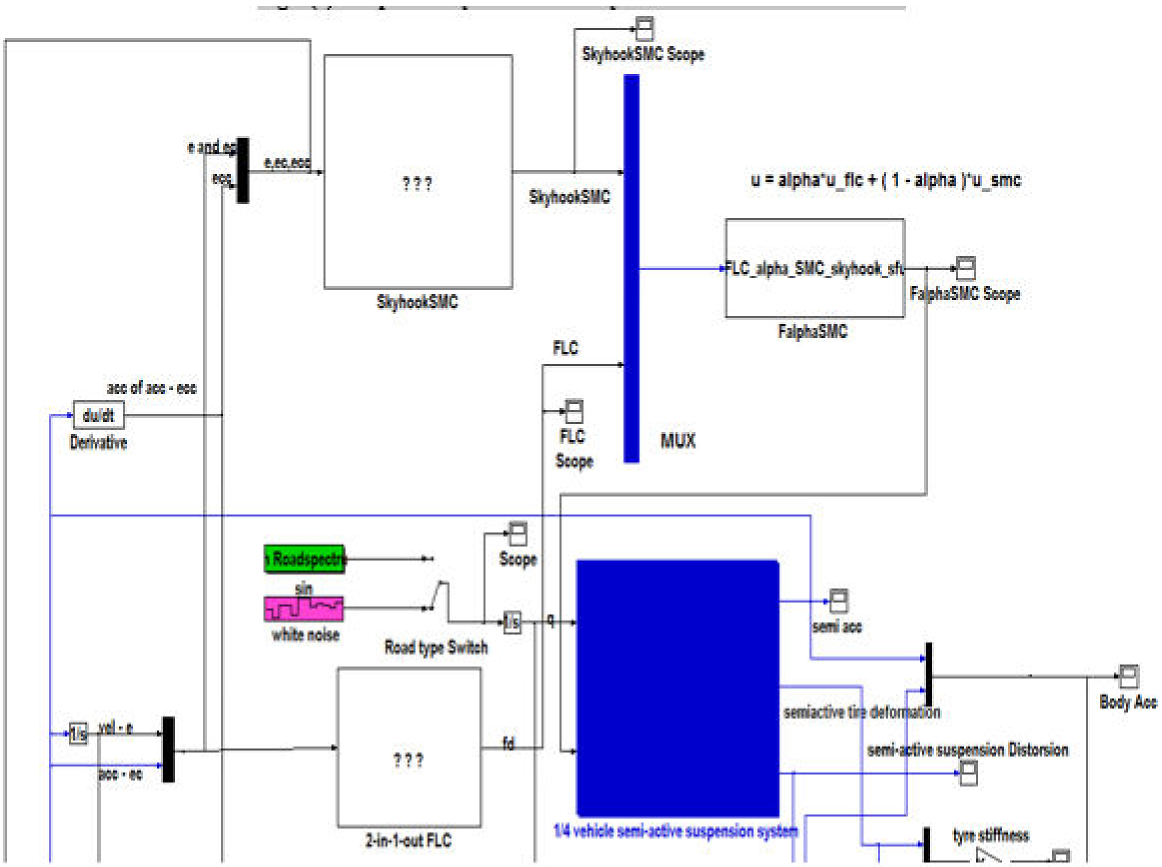

Fig 6(b): Simulink Model of Fuzzy control along with Skyhook controlled Suspension system

In this study, we explore the possibility of incorporating fuzzier-than-usual rules into the system in order to improve its performance:

Table 2: Fuzzy Rules

U			EC			
		NL	NS	Z	PS	PL
	NL	Z	Z	Z	Z	Z
E	NS	Z	PS	Z	NS	Z
	Z	PM	PS	Z	Z	NM
	PS	PM	PM	NS	NM	NM
	PL	PS	PS	NS	NL	NL

IV. RESULT AND DISCUSSION

Fig. 7 displays every system response plot in its entirety. The spectrum of reactions seen in the first and steady-state stages serve as more examples of the results. “By using the Fourier transform of the body acceleration/road displacement vs the frequency in hertz, Fig 8 is produced. Since the human body is most sensitive to accelerations in the frequency range of no more than ten Hurtz, Figure 9 is once again shown in an enlarged view to demonstrate how all four methods reduce body acceleration". This figure shows that the hybrid controller we have suggested delivers the most diminutive acceleration resonance peak.

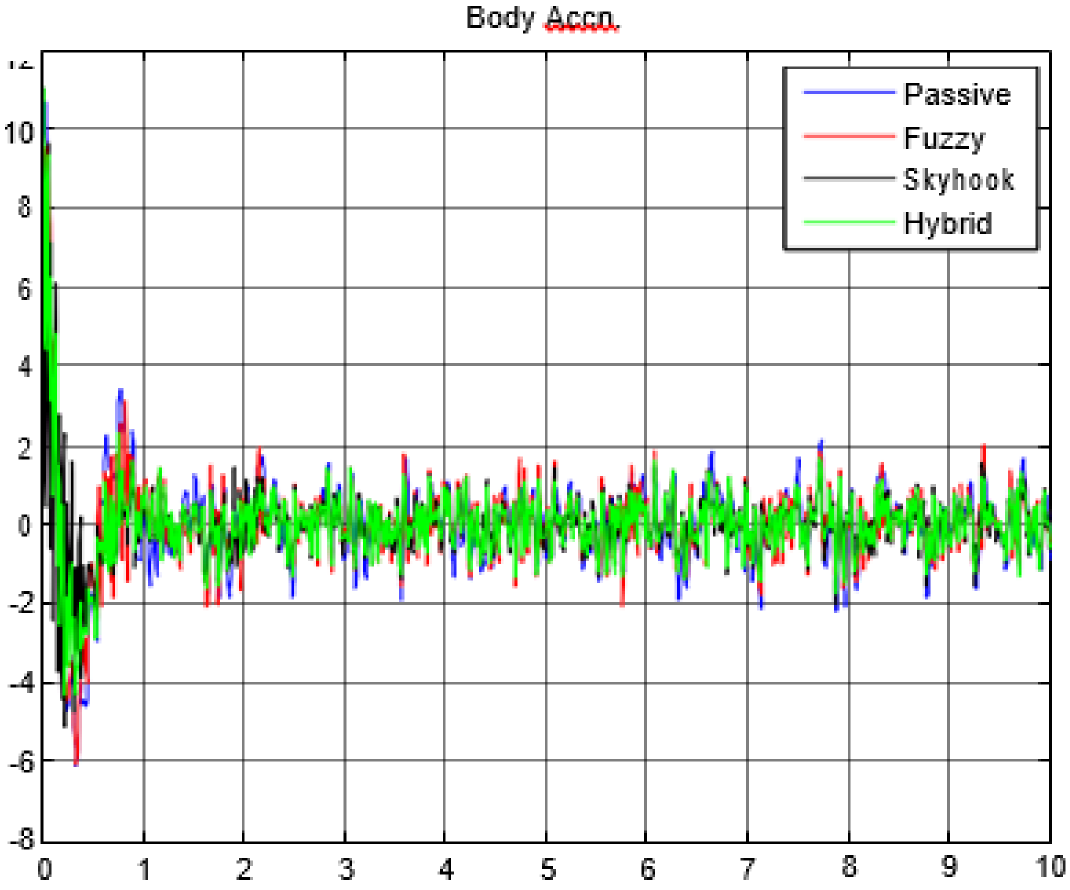

Fig 7: Combined Plot of Body Acc

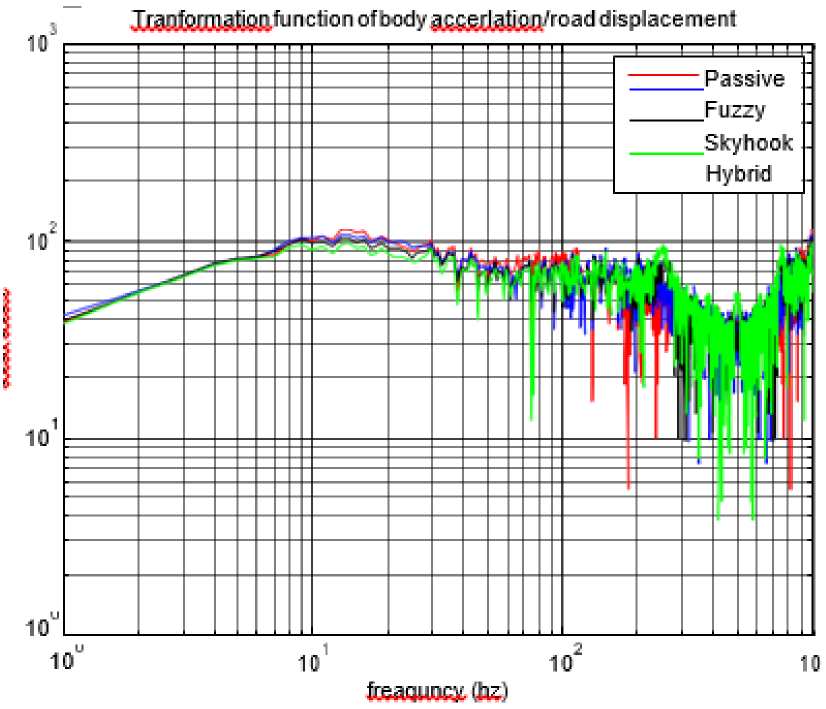

Fig 8: Transformation Function of Body Acceleration

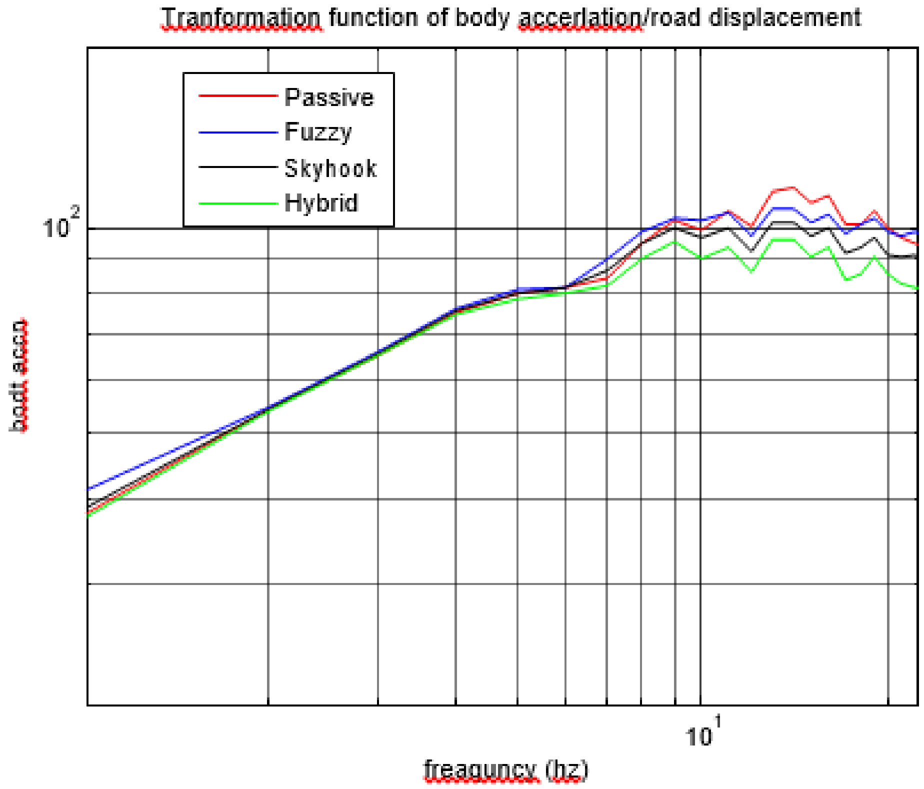

Fig 9: Acceleration's Role in Body Transformation (Enlarge View)

V. CONCLUSION

Additional 5x5 fuzzy rules are considered in this work to improve the conventional fuzzy inference system-based suspension control mechanism. It has been found that adopting this cutting-edge fuzzy logic controlled system in hybridization with traditional sliding mode nonlinear control theory significantly reduces body aberration brought on by road vibrations. Additionally produced is the body's acceleration's power spectrum in the frequency domain. It also validates the adder fuzzy rule hybrid suspension control mechanism's reduction of the resonant peak, which can enhance ride comfort.

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