

Fuzzy Rule in Sliding Mode Control Procedure for Vehicle Vibration Reduction

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Abstract-The vehicle suspension maintains a controllable dampening traction force between the tyres and paved surface to support and isolate the vehicle body and cargo from road vibrations caused by surface roughness. Semi-active suspension in modern luxury cars offers accuracy and dependability, improving ride comfort while consuming less power. In order to improve the ride comfort of a semi-active car suspension, we have proposed the construction of a hybrid system that combines fuzzy logic control and skyhook theory. For a car with semi-active suspension, a 2-degree-of-freedom dynamic model is simulated using Matlab/Simulink with a focus on the performance of the ride comfort for the passenger.

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

1. Introduction:

Skyhook damping and fast load leveling, which are now being developed for actual large-scale production applications, were born out of the quarter-vehicle model, which was initially developed to investigate active suspension capabilities. Karnopp et al. introduced the ideal Skyhook control strategy in 1974, which is regarded as one of the most effective due to its simplicity. The basic idea is to use a damper called a "skyhook" that can be controlled to connect the vehicle's sprung mass to the stationary sky. This damper could produce the controllable force of a skyhook and reduce vertical vibrations caused by any kind of road disturbance. Between the sprung mass and the inertia frame, their initial work makes use of only one inertia damper. A semi-active system as well as an active system can use the skyhook control. In practice, the skyhook control law was intended to approximate the force that would be generated by a damper fixed to an inertial reference known as the "sky" by modulating the damping force with a passive device.

The skyhook control has the ability to significantly lower the sprung mass's resonant peak, resulting in improved ride quality. A soft switching control law is introduced for the major sliding surface switching by borrowing this idea to reduce the sliding chattering phenomenon. This is done in order to achieve good switch quality for the Skyhook SMC.

Emelyanov devised variable structure control (VSC) with sliding mode control in the early 1950s and published it in the 1960s. Subsequent work was developed by a number of scholars. A reliable and effective control technique for intricate high order nonlinear dynamical systems is sliding mode control (SMC)..

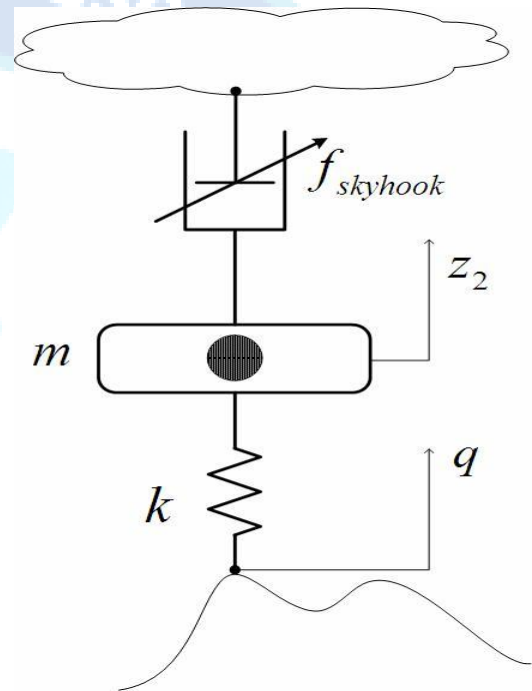


Fig 1: Ideal Skyhook control scheme.

The ability to decouple system motion into independent partial components of lower dimension and reduce the complexity of the system control and feedback design are the primary benefits of sliding mode control's low sensitivity to a system's parameter changing under various uncertainty conditions. Chattering, a common problem in control systems, is a major disadvantage of traditional SMC. A lot of literature has been written about SMC in recent years, and it has discussed how traditional SMC can be improved to improve performance and reduce chattering.

Our goal is to create a hybrid control system that combines the skyhook surface sliding mode control method with the fuzzy logic control method. This system will be used on a semi-active vehicle suspension system to improve ride comfort. A dynamic model of a vehicle's semi-active suspension system with two degrees of freedom is presented, with the passenger's ride comfort as the primary focus. The software MATLAB/SIMULINK will be used to design it.

2. Related Work:

M. Kondalu and co al. (2012) [5], worked on fuzzy logic-based control systems that make it easy and effective to

control systems that are extremely complex and imprecise. Fuzzy-based control systems can only be used in automotive and industrial settings because there isn't a simple hardware design that can change the parameters of the fuzzy controller to adapt to changes in the operation environment or plant system behavior. A controller's method of control that must adjust to a controlled system with parameters that fluctuate or are initially uncertain is called adaptive control. An adaptive controller has a distinct architecture with two loops—a control loop and a parameter adjustment loop—despite not having a formal definition.

Kothandaraman Rajeswari et al. Particle Swarm Optimization (PSO) was proposed by al. (2012) [4] for the purpose of fine-tuning the Adaptive Neuro Fuzzy Controller (ANFIS) for the vehicle suspension system. The training data set for the vehicle suspension system is obtained with the help of the LQR controller. Formulating ANFIS, which approximates the actuator output force as a function of system states, makes use of the subtractive clustering technique. The PSO algorithm looks for the best radii for ANFIS that uses subtractive clustering. The cost function is based on minimizing the difference between the actual and approximated output, and training takes place off-line. The simulation results show that the vehicle suspension system based on PSO-ANFIS has better road holding and ride comfort.

LIU Yanqing et al. al. [3], on semi-active systems with varying stiffness and damping, excellent performance has been demonstrated. However, the majority of applications make it difficult to implement conventional devices for controlling variable stiffness because they are complicated. A new arrangement with two constant springs and two controllable dampers is proposed to address this issue. The proposed system is the subject of theoretical and experimental analyses in this work. The system's stiffness is controlled through the use of a Voigt element and a spring in series. A constant spring and a damper that can be controlled make up the Voigt element. Controlling the damper in the Voigt element alters the system's equivalent stiffness, and the second damper, which is parallel to the other elements, provides variable damping. Two magneto-rheological fluid dampers serve as the controllable dampers in the experimental implementation of the proposed system. Eight different control strategies are looked at, including damping on-off for soft and stiff suspensions, damping on-off for low and high damping, stiffness on-off for low and high damping, and damping and stiffness on-off control. The system's time and frequency responses to sinusoidal, random, and impulse excitations demonstrate that the proposed system can control variable stiffness and damping. For a wide range of excitations, the system with damping and stiffness on/off control provides excellent vibration isolation.

Slotine et al. In order to achieve precise tracking in a class of non-linear, time-varying systems in the presence of disturbances and parameter variations, al. (1982) [2] developed a method of feedback control. The idealized form

of the method employs piecewise continuous feedback control, resulting in the state trajectory "sliding" through the state space along a sliding surface that changes over time. The perfect tracking is achieved by this idealized control law; However, it generates an undesirable high frequency component in the state trajectory due to implementation flaws. In order to correct this, we demonstrate how continuous control laws can be used to approximate the discontinuous control law in order to reduce the amount of high frequency signal and achieve robust tracking with a predetermined accuracy. A two-link manipulator with variable loads in a flexible manufacturing system is controlled using this approach.

John Y. Hung et al. provide a tutorial on variable structure control using sliding mode, (1993) [1]. This powerful control system design approach's fundamental theory, main results, and practical applications will be presented in a concise manner. Controlling nonlinear systems is a particularly appealing application for this strategy. In-depth discussion is given to prominent characteristics like invariance, robustness, order reduction, and control chattering. There are suggestions for dealing with chattering. Nonlinear as well as linear systems are taken into account. An extensive list of references and suggested future research areas are included.

3. Methodology:

Because it provides a convenient method for constructing nonlinear controllers through the use of heuristic information, fuzzy logic control is a practical alternative for a variety of challenging control applications. The experience of an operator who has acted as a human in the loop controller provides the rule-base for the fuzzy logic control. It actually offers a human experience that is based on representing and putting into practice human concepts regarding high performance control.

Figure depicts the FLC's structure for the 2-DOF SA suspension system. 2, the experts' knowledge is described using the "If Then" rule base. Fig. The FLC inference mechanism can be driven by the 2-in-1-out FLC rule-base cloud known as 2. A set of linguistic description rules based on conceptual expertise derived from typical human situational experience defines the FLC rule-base. Based on previous experience with semi-active damping force control during body acceleration changes for ride comfort, the 2-in-1-out FLC rule-base is provided for the 2-DOF SA suspension system's ride comfort. The most important linguistic control rules are as follows: 1) The SA damping force rises in tandem with an increase in body acceleration; 2) On the other hand, the SA damping force decreases when the body acceleration decreases.

Additionally, the rule-based 3D cloud map plot in Figure 1 depicts the relationship between one semi-active control force output (U) and two inputs of error (E) and the change in error (EC). Table 1 provides the complete 2-in-1-out FLC rule-base, which can map the FLC rule-base to the output control force based on the semi-active suspension body acceleration input data.

Fuzzification is the process of mapping variables from practical space to fuzzy space by decomposing system inputs into fuzzy sets. Fuzzification makes it possible to express the system's inputs and outputs in linguistic terms, making it easier to apply rules to express a complex system. For two inputs of Error(E) and Error in Change(EC) and one output of FL, there are seven elements in the fuzzy sets in the FLC for 2-DOF SA suspension system: for the Fuzzy Inference System (FIS): NL, NM, NS, ZE, PS, PM, and PL. De-fuzzification maps variables from fuzzy space to practical space, which is the opposite of fuzzification.

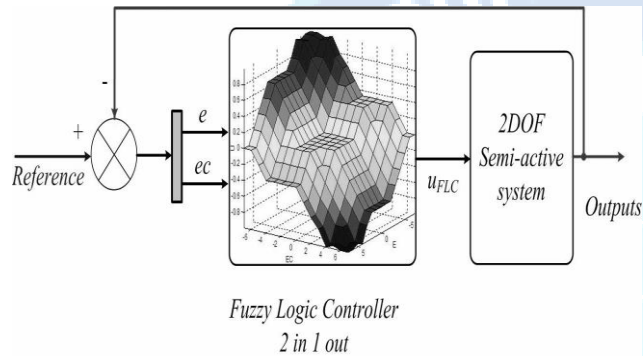


Fig 2: 2-in-1-out fuzzy logic control workflow diagram.

In essence, a membership function (MF) is a generalization of the indicator function found in classical sets. It specifies the mapping of each point in the input space to a membership value between 0 and 1 in the function. The membership function (MF) for the 2-DOF SA suspension system is triangular in shape; the MF for E is depicted in Figure 3, and the MFs for EC and U share the same element range. This fuzzy set is used to interpret the inputs of E and EC, as well as the degree of membership.

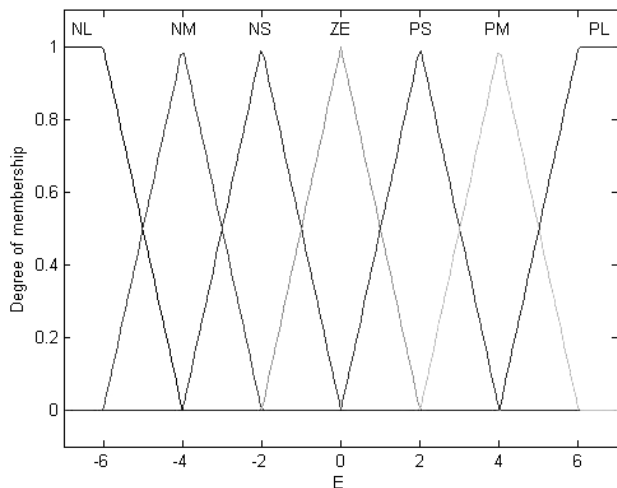


Fig 3. Triangular-shaped membership function for FLC controller.

Model Of Force Balance Equation For Un-Sprung Mass:

We have linked these road disturbance signals to the unsprung mass force balance equation (1) in this model. The following parameters are used in this equation: 1). This model addresses force condition for un-sprung mass which is displayed in Fig 4

This figure comprises of information input blocks addressing the reenactment boundaries utilized in the power condition of 2-DOF SAS framework.

Figure 5 depicts the unmasked data input block. It consists of constant input blocks with the parametric values m_1 , m_2 , k_1 , k_2 , c_0 , f_r , and g . Each constant input passes through a multiple block of size 7×1 because mux output is mentioned as a simulation parameter. A de-multiplexer is used to de-multiplex the multiplexed output, and we are taking into account the mass m_1 and displacements z_1 and z_2 from the product block's output. Summer block generates $m_1 z_1''$ in this model as the force acting on unsprung mass m_1 , where z_1'' represents the acceleration of m_1 caused by body inertia and load disturbance. This force is the sum of $k_1(z_1 - q)$, $k_2(z_1 - z_2)$, $c_0(z_1' - z_2')$, $-m_1 g$, and $f_r (=c_2(z_2' - z_1'))$, and the product block is used to multiply the result of sum up by $1/m_1$. The product block is providing z_1 in this manner.

Table 1: 2-DOF SA suspension parameters

m_1	Un-sprung mass, kg	36
m_2	Sprung mass	240
c_2	Suspension damping coefficient, Ns/m	1400
k_1	Tire stiffness coefficient, N/m	160000
k_2	Suspension stiffness coefficient, N/m	16000
G	Gravity acceleration, m/s^2	9.81
K_e	FLC scaling gain for e	-1
K_{ec}	FLC scaling gain for ec	-10
K_u	FLC scaling gains for u	21
C_0	SkyhookSMC damping coefficient	-5000
Δ	Thickness of the sliding surface	28.1569
Λ	Slope of the sliding surface	10.6341
N_0	Reference space frequency, m^{-1}	0.1
$P(n_0)$	Road roughness coefficient, $m^3/cycle$	250×10^{-6}
V_0	Velocity, km/h	72

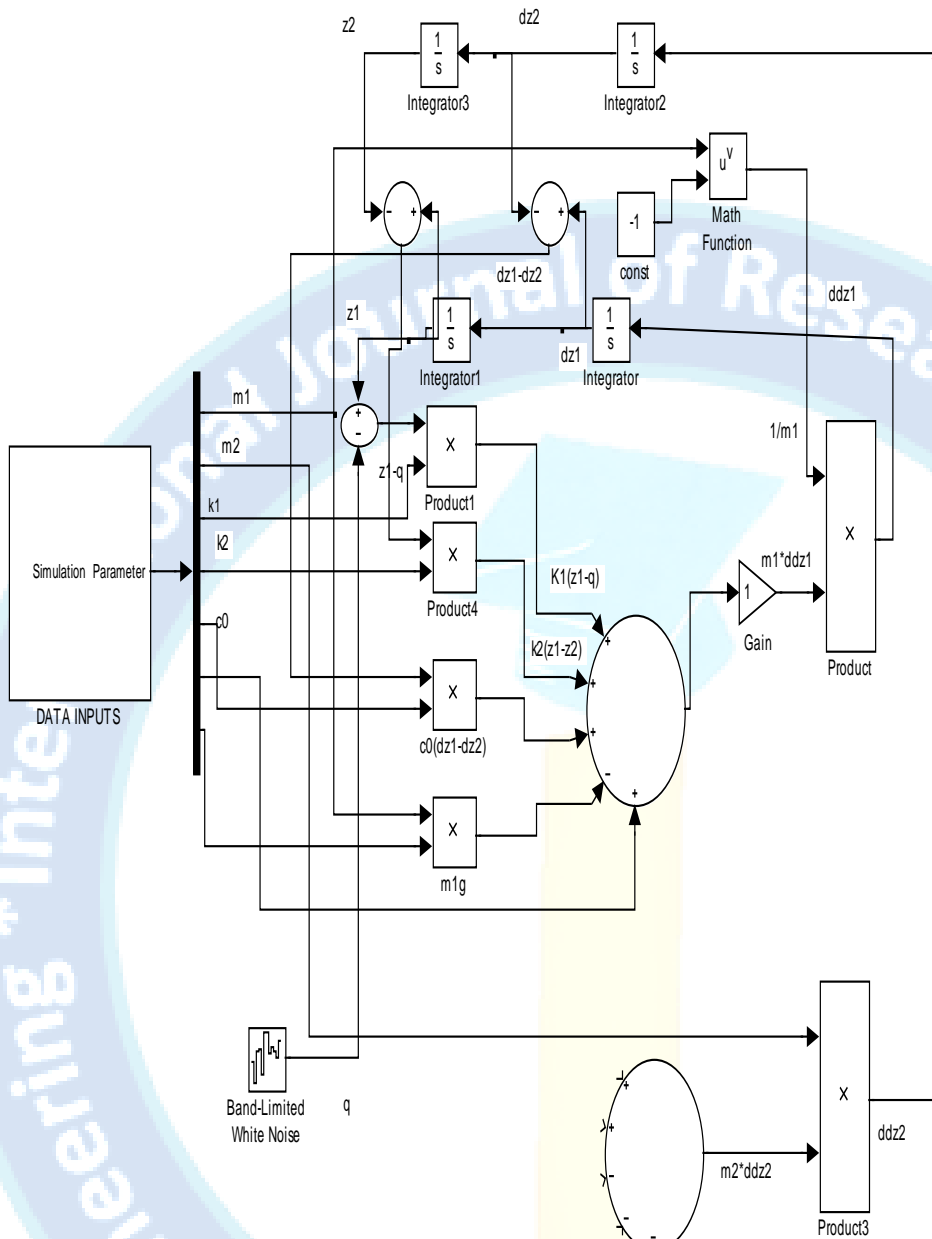


Fig 5 Model of Force Balance Equation for Un-sprung Mass

In this paper we have considered following added fuzzy rules to enhance the accuracy of the system 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

4. Result and Discussion:

Fig. 7 displays every system response plot in its entirety. The spectrum of various reactions seen in both the first stages and the steady state stage 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 10 hertz, Figure 9 is once again shown in an enlarged view to demonstrate how all four methods reduce body acceleration. This fig. makes it evident that the hybrid controller we've suggested delivers the least amount of acceleration resonance peak.

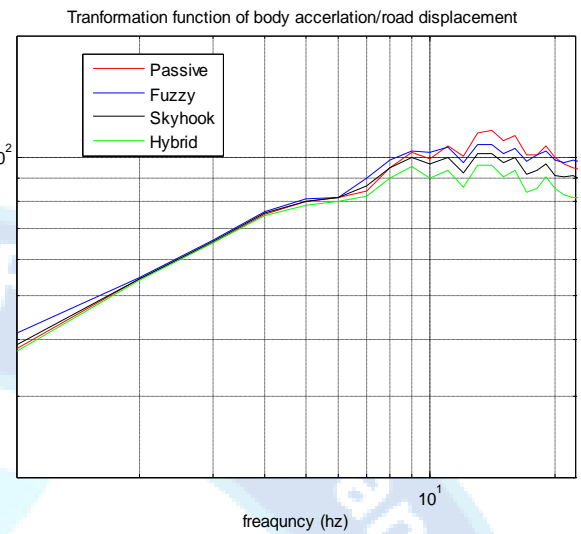


Fig 9: Transformation Function of Body Acceleration (Enlarge View).

5. Conclusion:

Additional 5x5 fuzzy rules are taken into consideration 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 greatly 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 added fuzzy rule hybrid suspension control mechanism's reduction of the resonant peak, which can enhance ride comfort.

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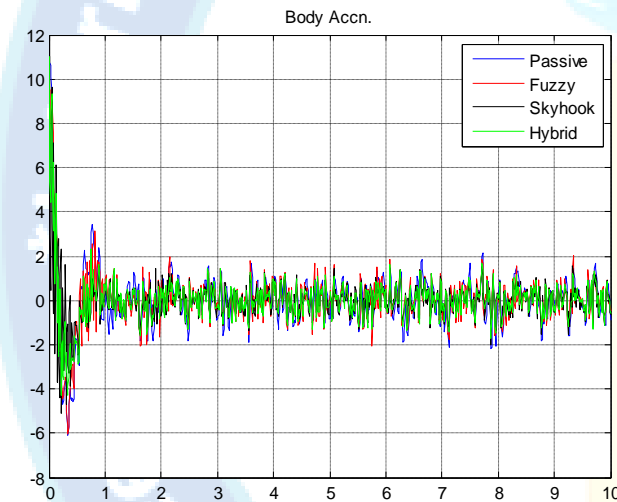


Fig 7: Combined Plot of Body Accn.

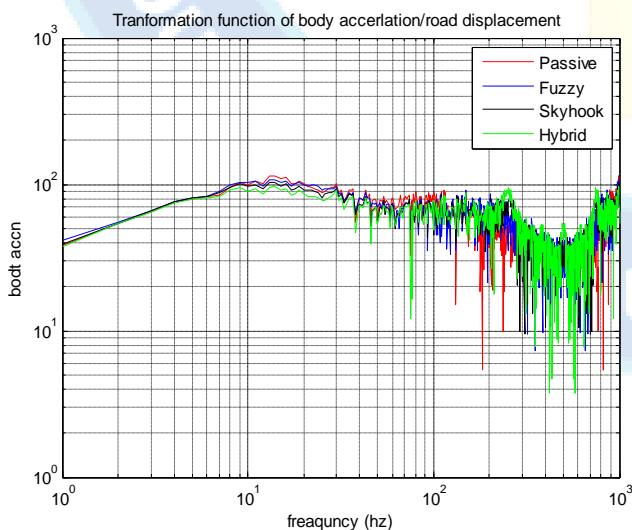


Fig 8: Transformation Function of Body Acceleration.



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