TURNITIN Enhancing Comfort and Handling in Semi-Active

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Enhancing Comfort and Handling in Semi-Active Suspension Systems with Fuzzy Controller

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***Abstract*— The pursuit of driving comfort and superior handling performance in vehicles has been a long-standing goal in the field of automotive engineering. The emergence of semi-active suspension systems represents a significant leap forward, offering a dynamic compromise between traditional passive systems and complex active systems. However, achieving optimal control of semi-active dampers remains an important challenge. The introduction of fuzzy controllers revolutionized this landscape, introducing a new approach to suspension control. This paper presents a comprehensive exploration of the development, principles, and applications of fuzzy controllers, demonstrating their transformative impact on vehicle dynamics. The controller outcomes indicate that the sprung mass acceleration, tire load, and suspension distortion were significantly reduced with average percentages of 15%, 2%, and 5%, respectively.**

Keywords*— *Fuzzy controller, Suspension, Semi-Active, Comfort, Handling, Frequency response

I. INTRODUCTION

With the development of technology, especially automotive, society is increasing increasingly stringent requirements for the overall quality of vehicles [1]. The quality of a vehicle in the form of comfort and safety is determined by the damper or suspension system. Recently, enhancing the vibration-damping capabilities of suspension systems for improved vehicle stability has been the primary focus of research in active control suspension technology. [2,3]. The suspension system functions to transfer force and torque between the wheels and the body while supporting impact loads due to uneven road surfaces. The suspension system will reduce vertical body vibrations ensure driving comfort and safety and increase control stability [4-7]. Commonly used control strategies for semi-active suspensions include optimal control, skyhook control, sliding mode control, blur control, and PID control. Skyhook control and sliding mode control demonstrate a degree of resilience but are not specifically engineered to achieve the best possible system performance [8-10]. Active suspension systems have the capability to store, release, and supply energy to the system. In this setup, sensors are employed to gauge vehicle performance parameters, including vertical body and wheel acceleration, serving as input for the active control system. Although active suspension systems provide better control performance, semi-active suspension has the advantage of not requiring external energy.

To create a suspension system that works optimally, a vehicle suspension design is needed that can study road characteristics [11, 12]. Selecting optimal damping requires a compromise between a harder damper "safe damper" and a softer damper "more comfortable". Choosing the right damper setting becomes challenging due to its reliance on both the road surface and the driver's chosen driving maneuver. To address this challenge, controlled dampening was introduced. In the graphical depiction of this issue, the traditional spring-damper combination is depicted as the point where the constant damping curve intersects with the constant spring stiffness curve. In contrast, the controlled damper has the flexibility to represent any position on a constant spring stiffness curve, offering the ability to be fine-tuned for optimal safety or comfort [13].

Semi-active suspension is a suspension system that can adjust suspension characteristics automatically based on road conditions and vehicle speed [14]. This system uses actuators to regulate suspension characteristics, such as stiffness and damping, so as to increase comfort and safety (vehicle stability) [15,16]. Semi-active suspension has advantages compared to passive suspension and active suspension. The passive suspension only has fixed suspension characteristics, while active suspension requires complex sensors and controls [17]. Semi-active suspension can provide better comfort compared to passive suspension and is simpler than active suspension.

Artificial Intelligence (AI) is a branch of computer science that focuses on developing algorithms and technology to enable machines to perform tasks that usually require human intelligence, such as voice recognition, facial recognition, and decision-making [18]. AI can be used to improve the performance of semi-active suspension systems by optimizing suspension characteristics based on road conditions and vehicle speed. AI can learn patterns from data obtained from sensors and produce better decisions compared to pre-programmed algorithms [19, 20]. In recent years, the automotive field has witnessed significant developments in the application of AI to vehicle suspension systems. Some AI techniques that have become the focus of research and development in the context of vehicle suspension systems include artificial neural networks and genetic algorithms. Artificial neural networks are used to process data from various vehicle sensors and make quick decisions to adjust the suspension [21]. Fuzzy logic allows the system to combine mathematical aspects with human judgment in making decisions about suspension settings. A genetic algorithm is used to optimize suspension parameters automatically based on algorithm evolution [22]. The application of AI to vehicle suspension is expected to improve vehicle performance in various road conditions.

This research uses a simple and practical approach to develop a semiactive controller based on a fuzzy controller to improve vehicle comfort and safety. This research also motivated the development of a large number of non-conventional controller schemes that perform well compared to conventional alternatives. Simulation tests will be carried out using fuzzy-based software to test the performance of the semi-active suspension system. It was found that the development of fuzzy-based semi-active suspension can improve vehicle comfort and stability.

II. METHOD

Fig. 1 illustrates a quarter-car diagram, where z_s, z_u, and z_r are the sprung-mass, the unsprung-mass, and the road displacements, respectively. In this model, the specified values for the parameters (sprung mass (m_s), unsprung mass (m_u), coil spring constant (k), tire spring constant (k_t), and rattle space (z_s-z_u)) are 460 kg, 36 kg, 20.000 N/m, 186.000 N/m, and 91 mm, respectively. The objective of the control is to manipulate the damping force Fd using a desired current input I to the magnetorheological (MR) fluid, solely based on measuring the relative displacement $z_s - z_u$.

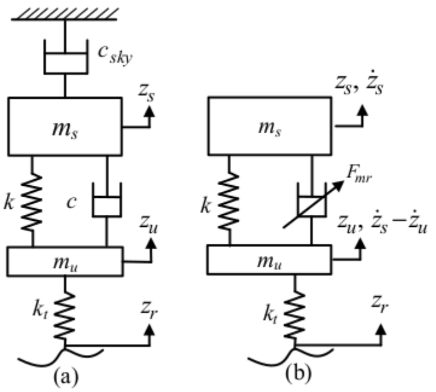

Fig 1. Illustrates quarter-car models, showcasing (a) the modified skyhook control and (b) the equivalent representation of the modified skyhook control.

The equations of motion are as follows [24-26],

$$m_s \ddot{z}_s + c_1(\dot{z}_s - \dot{z}_u) + c_2 \dot{z}_s + k(z_s - z_u) = 0 \text{ (Fig. 1b).} \quad (1)$$

$$m_s \ddot{z}_s + \mu(\dot{z}_s - \dot{z}_u) + k(z_s - z_u) = 0 \text{ (Fig. 1b).} \quad (2)$$

here $\mu = \mu(c_1, c_2)$ represent the modified parameter. The equation describing the motion of the unsprung mass, derived from either (1) or (2), is expressed as

$$. m_u \ddot{z}_u + m_s \ddot{z}_s + k_t(z_u - z_r) = 0 \quad (3)$$

When comparing Figs. 1(a) and 1(b), the damping forces should be supplied as

$$F_{mr} = c_1 + c_2 \frac{\dot{z}_s}{(\dot{z}_s - \dot{z}_u)}, \quad (4)$$

here c_1 and c_1 are selected to be obtimized with regard to considerations of ride comfort, road holding, and road conditions. Introducing the concept of making the damping force dependent on multiple parameters, the following control law is suggested.

$$\begin{aligned} u &= c_1(a, f)(\dot{z}_s - \dot{z}_u) + c_2(a, f)(\dot{z}_s) \\ &= F_{mr}(\dot{z}_s - \dot{z}_u), \end{aligned} \quad (5)$$

here u represent a control input, a is a coefficient of the road roughness, and f is the excitation frequencies of the road. It is evident that the damping force F_{mr} is influenced by both the relative velocity $\dot{z}_s - \dot{z}_u$ and the modified current I. The control approach for semi-active suspension systems closely resembles that of active suspensions, except for the limitations imposed by the specified equations.

$$u = \begin{cases} c_1(a, f)(\dot{z}_s - \dot{z}_u) + c_2(a, f)(\dot{z}_s), & \text{if } \dfrac{\dot{z}_s}{\dot{z}_s - \dot{z}_u} > 0 \\ c_{\min}(\dot{z}_s - \dot{z}_u), & \text{if } \dfrac{\dot{z}_s}{\dot{z}_s - \dot{z}_u} < 0. \end{cases} \quad (6)$$

It is important to highlight that when absolute and relative velocities align, the semi-active control input is proportionate to both velocities. Conversely, if the velocities are not in the same direction, the semi-active control input needs to assume its minimum feasible value. While the control input is determined by Eq. (6), the practical control input must be derived from the variable damper. Experimental findings, as depicted in Fig 2, indicate limitations on the actual control input, as outlined below.

$$F_d = \begin{cases} F_d^{\max}, & \text{if } F_d^{\max} \le u \\ u, & \text{if } F_d^{\min} \le u \le F_d^{\max} \\ F_d^{\min}, & \text{if } F_d^{\min} \ge u \end{cases} \quad (7)$$

where $F_d^{\max}$ and $F_d^{\min}$ represent the highest and lowest achievable actual damping forces at a specific relative velocity. Employing hydraulic dampers may be effective in mitigating road disturbances within the 1-4 Hz range but may prove less effective for higher frequencies [26]. Given the swift response time of the fluid in an MR damper, it becomes adaptable to a wider spectrum of road conditions. A distinctive attribute of MR fluids lies in their hysteresis characteristics, evident in the expansion and contraction processes.

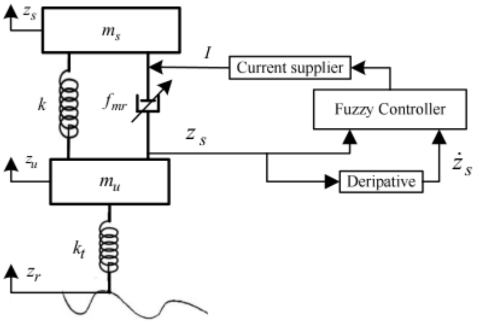

Fig. 2 Fuzzy Controller Scheme for quarter car model.

III. RESULTS AND DISCUSSIONS

In this study, a fuzzy logic control algorithm is employed to dampen vibrations in a semi-active suspension system. Lotfi Zadeh initially introduced this algorithm [14], and it has since proven to be a potent tool for control system applications in mechatronic-based devices. The specific fuzzy controller is situated between the passenger seat and the sprung mass of the vehicle. The inputs to this controller include the sprung acceleration and relative velocity ($\dot{z}_s - \dot{z}_u$), while the output is the desired damping force (Fmr). The linguistic grades for the input and output variables in the fuzzy logic controller are defined as Positive Large (PL), Positive Small (PS), Zero (Z), Negative Small (NS), and Negative Large (NL), with the addition of Positive Medium (PM) and Negative Medium (NM) for the output. The membership function plots designed for these variables are depicted in Fig. 3.

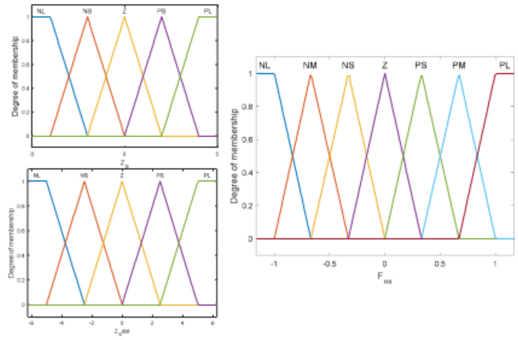

Fig. 3 Fuzzy membership function of inputs and output.

Sprung mass acceleration is an important parameter in vehicle dynamics and suspension systems, as it directly impacts ride comfort and handling characteristics. Two common approaches to control sprung mass acceleration in vehicle suspensions are semi-active and passive systems. In this discussion, we will compare these two methods as shown in Fig. 4. It is clear the sprung mass acceleration with fuzzy controller is relatively smaller than passive one with average reduce about 15%.

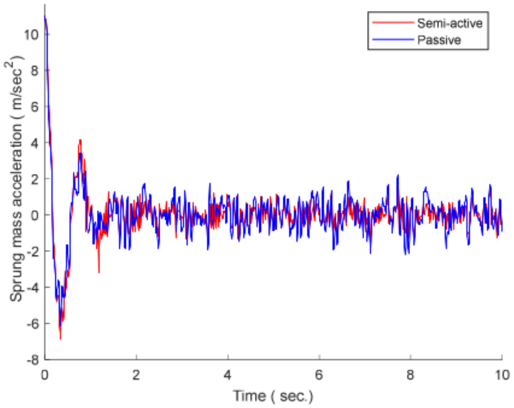

Fig. 4 Sprung mass acceleration: semi active vs passive

In a semi-active suspension system, understanding and managing tire load is crucial for achieving optimal performance in terms of both ride comfort and handling. The load on each tire directly affects factors like traction, tire wear, and overall vehicle stability. In real-world driving conditions, the load on each tire is constantly changing due to factors such as acceleration, deceleration, cornering, and road surface variations. A semi-active suspension system must be able to adapt to these dynamic load changes effectively. Optimizing tire load ensures that each tire maintains good contact with the road surface. This is essential for maximizing traction, especially during acceleration and braking. By adjusting suspension damping in response to load changes, a semi-active based fuzzy controller system can enhance traction as shown in Fig. 5. By effectively managing tire load, a semi-active suspension system can provide a smoother and more comfortable ride. It can absorb road shocks and impacts, reducing the harshness experienced by occupants. In this research the tyre load was reduced into 2%.

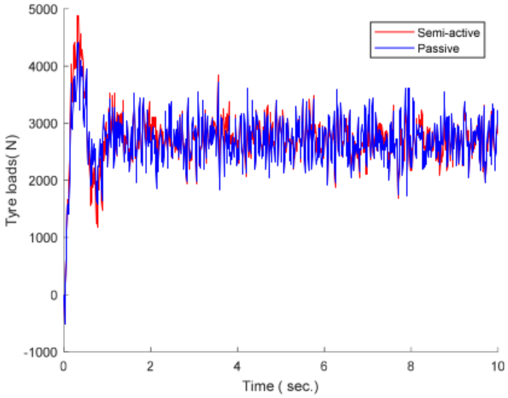

Fig. 5 Tyre Load response: Semi active vs passive

Suspension distortion typically refers to deviations from the intended behavior of a suspension system due to various factors, including external forces, component wear, and dynamic load changes. In the context of a semi-active suspension system, distortion can arise from the system's response to changing conditions. Semi-active systems, while more adaptable than passive systems, may still exhibit a slight delay in their response to changing conditions. This delay can lead to temporary distortions in suspension behavior as the system catches up with the new load distribution. The accuracy of sensors used in a semi-active system is crucial. Inaccurate sensor data can lead to incorrect adjustments in damping rates, causing distortion in suspension behavior. In the Fig. 6, it is indicated that the suspension distorsion semi active with fuzzy controller is higly reduced with average of 5%.

In the developed semi-active suspension system with a fuzzy controller, the frequency response of the transformation function for the relationship between tire load and road displacement is a critical aspect. This response characterizes how the system reacts to different frequencies of input from the road surface. The frequency response of the transformation function provides insight into how the suspension system behaves dynamically in response to varying road surface conditions. It reveals how the system attenuates or amplifies specific frequencies. The frequency response consists of both an amplitude and phase component. The amplitude response indicates the system's gain or attenuation at different frequencies, while the phase response represents the time delay in the system's response. Effective damping in the system aims to suppress resonant peaks, ensuring stable and controlled behavior. The fuzzy controller, with its linguistic rules and adaptability, can enable the transformation function to respond differently to various frequency components in the road surface. This adaptability is crucial for providing a comfortable ride across a range of road conditions. In Fig. 7., the sprung mass acceleration response is highly better in the frequency range of about 6 to 100 Hz. For the higher frequency, the passive one is better. The design of the transformation function involves making trade-offs between factors like ride comfort, handling performance, and energy efficiency. These trade-offs should align with the desired objectives of the vehicle. the transformation function in a semi-active suspension system with a fuzzy controller is a critical component that determines how the system responds to inputs related to sprung mass acceleration and road displacement. It enables the system to adapt to changing conditions, balance ride comfort and handling, and make informed control decisions in real-time.

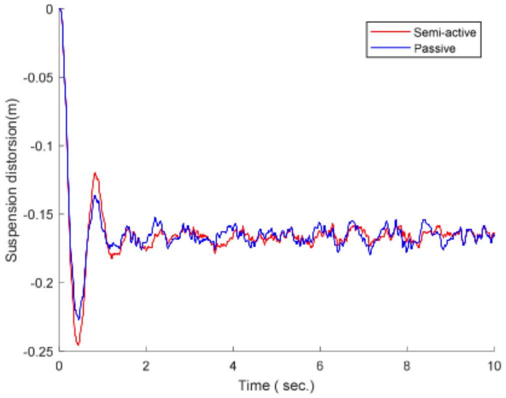

Fig. 6 The Suspension Distortion

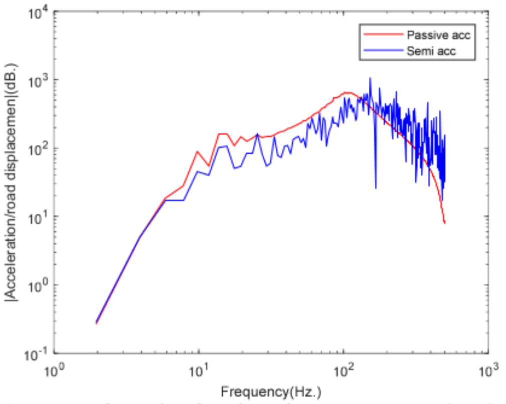

Fig. 7 Transformation function of sprung mass acceleration / road displacement

Tyre load plays a significant role in balancing ride comfort and handling performance while ensuring stability and safety across a range of driving conditions. Proper design and tuning of the frequency response are essential for achieving optimal suspension performance. As shown in the Fig. 8, the except in the low frequency (less than 7 Hz) the performance of tyre load is better than passive one. One notable characteristic often observed is that the tire load response tends to excel, particularly in higher frequency ranges, while potentially showing some limitations at low frequencies. The system's strength lies in its ability to respond effectively to higher frequency inputs. This is crucial for maintaining stability and control during dynamic driving situations, such as quick steering maneuvers or sudden changes in road surface conditions.

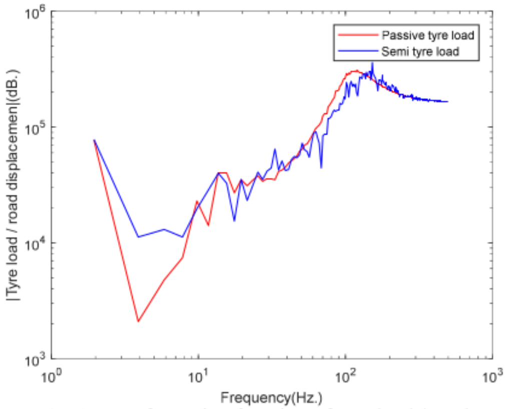

Fig. 8 Transformation function of tyre load / road displacement

The development of semi-active suspension systems with fuzzy controllers has shown promising advancements in improving ride comfort and vehicle handling. This discussion aims to delve into the frequency response characteristics of suspension distortion with respect to road displacement in such systems. Understanding how the suspension responds to different frequencies of road input is crucial for optimizing performance and ensuring a smooth ride. The frequency response of a semi-active suspension system refers to how the system reacts to road displacement at different frequencies. The goal is to minimize suspension distortion, which is the deviation of the vehicle's response from the desired ride quality. Frequency response analysis is essential in understanding how the system behaves under various driving conditions and road irregularities. The frequency response of transformation function of tyre load toward the road displacement as shown in Fig. 9 shows that the distorsion is highly reduce in the frequency less than 8 Hz using passive suspension and significantly reduced in the high frequency using semi active one. Achieving an optimal frequency response requires careful tuning of the fuzzy controller, considering various factors such as road profile, vehicle dynamics, sensors, and actuators. By doing so, automotive engineers can design vehicles that offer a smoother and more controlled ride across a wide range of road conditions.

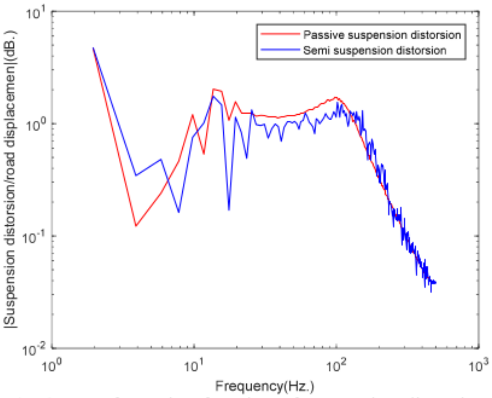

Fig. 9 Transformation function of suspension distortion /road displacement

IV. CONCLUSIONS

The ability to adapt to dynamic load changes in real-time allows for improved traction, ride comfort, and handling performance. Through the use of advanced sensors and control algorithms, these systems can enhance the overall driving experience and safety of the vehicle. Through a comprehensive examination of their development, principles, and applications, this paper highlights the transformative impact of fuzzy controllers on vehicle dynamics. The simulation results demonstrate significant improvements, with sprung mass acceleration, tyre load, and suspension distortion exhibiting an average reduction of 15%, 2%, and 5%, respectively. These findings underscore the potential of fuzzy controllers in substantially enhancing the performance and ride quality of vehicles equipped with semi-active suspension systems.

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REFERENCES

[1] A. Soliman, M. Kaldas, "Semi-active suspension systems from research to mass-market – A yreview," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 40, pp. 1005-1023, 2021.

[2] S. J. shao, C. B. Ren, T. H. Yan, "Study on the stability and vibration reduction of nonlinear active suspension system with time-delayed feedback control," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 40, pp. 1048-1058, 2021.

[3] E. T. AMA, "Advanced Hydro-Pneumatic Semi-Active Suspension System," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 20, pp. 93-103, 2001.

[4] M. Gong,H. Chen, "Variable damping control strategy of a semi-active suspension based on the actuator motion state," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 39, pp. 787-802, 2020.

[5] S. Kurczyk, M. Pawelczyk, "Fuzzy Control for Semi-Active Vehicle Suspension," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 32, pp. 217-225, 2013.

[6] M. Corno, O. Galluppi, G. Panzania, A. Sinigaglia, P. Capuano, J. Cecconi, S. M. Savaresi, "Design and validation of a full body control semi-active suspension strategy for a supercar, *IFAC-PapersOnLine*, vol. 52, pp. 667-672, 2019.

[7] A. M, A. E. Tawwab, "Twin accumulator semi active suspension system with preview control," *Journal of low frequency noise, vibration and active control*, vol. 26, pp. 283-294, 2007.

[8] S. Li, J. Zhao, Z. Zhang, "Investigation on linear quadratic gaussian control of semi-active suspension for three-axle vehicle," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 40, pp. 1633-1648, 2021.

[9] Z. Houzhong, L. Jiasheng, Y. Chaochuan, S. Xiaoqiang, C. Yingfeng, "Application of explicit model predictive control to a vehicle semi-active suspension system," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 39, pp. 772-786, 2020.

[10] J. D. Wu, C. J. Lin, K. Y. Kuo, "A study of semi-active vibration control for vehicle suspension system using an adjustable shock absorber," *Journal of low frequency noise, vibration and active control*, vol. 27, pp. 219-235, 2008.

[11] M. Ghoniem, T. Awad, O. Mokhiamar, "Control of a new low-cost semi-active vehicle suspension system using artificial neural networks," *Alexandria Engineering Journal*, vol. 59, pp. 4013-4025, 2020.

[12] Y. Guo, C. Ren, "Research on vibration reduction of semi-active suspension system of quarter vehicle based on time-delayed feedback control with body acceleration" *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 41, pp. 701-711, 2022.

[13] A. Soliman, M. Kaldas, "Semi-active suspension systems from research to mass-market–A review," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 40, pp. 1005-1023, 2021.

[14] G. B. H. Frej, X. Moreau, E. Hamrouni, A. B. Neto, V. Hernette, "Multi-modes control for semi-active suspension systems," IFAC-PapersOnLine, vol. 53, pp. 14407-14412, 2020.

[15] G. Savaia, S. Formentin, S. M. Savaresi, "Semi-active suspension control design via Bayesian optimization" IFAC-PapersOnLine, vol. 53, pp. 14312-14317, 2020.

[16] K. Sato, K. Hiramoto, "Vibration control of semi-active suspension by the neural network that learned the optimal preview control of MLD model," IFAC-PapersOnLine, vol. 55, pp. 515-520, 2022.

[17] H. N. Rafsanjani, A. H. Nabizadrh, "Towards human-centered artificial intelligence (ai) in architecture, engineering, and construction (aec) industry," Computers in Human Behavior Reports, vol. 11, pp. 100319, 2023.

[18] M. Yang, X. Ren, J. H. Cho, "Nonlinear controller supported by artificial intelligence of the rheological damper system reducing vibrations of a marine engine," Journal of Low Frequency Noise, Vibration and Active Control, vol. 42, pp. 1919-1936, 2023.

[19] J. H. Lee, H. J. Kim, B. J. Cho, J. H. Choi, Y. J. Kim, "Road bump detection using LiDAR sensor for semi-active control of front axle suspension in an agricultural tractor," IFAC-PapersOnLine, vol. 51, pp. 124-129, 2018.

[20] I. Ursu, F. Ursu, T. Sireteanu, C. W. Stammers, "Artificial intelligence based synthesis of semiactive suspension systems," *Shock and Vibration Digest*, vol. 32, pp. 3-10, 2000.

[21] S. Kurczyk, M. Pawel/czyk, "Fuzzy control for semi-active vehicle suspension," *Journal of Low Frequency Noise, Vibration and Active Control*, vol. 32, pp. 217-226, 2013.

[22] B. Basargan, A. Mihaly, P. Gaspar, "Cloud-based adaptive semi-active suspension control for improving driving comfort and road holding," IFAC-PapersOnLine, vol. 55, pp. 89-94, 2022.

[23] J. O, S. M. S, Nhlapo, L. J. Mpanza, "Model predictive control of half-car active suspension systems using particle swarm optimisation" IFAC-PapersOnLine, vol. 53, pp. 14438-14443, 2020.

[24] A. Turnip, JH Panggabean, "Hybrid controller design based magneto-rheological damper lookup table for quarter car suspension", Int. J. Artif. Intell, vol. 18, pp. 193-206, 2020.

[25] A. Turnip, S. Park, KS. Hong, "Sensitivity control of a MR-damper semi-active suspension", International Journal of Precision Engineering and Manufacturing, vol. 11, pp. 209-218, 2010.

[26] A. Turnip, KS. Hong, "Road-frequency based optimisation of damping coefficients for semi-active suspension systems", International Journal of Vehicle Design, vol. 63, pp. 84-101, 2013.

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