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Pressing Mechanism Design and Performance Analysis for Brake Pedal System at Low-Speed Driving

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ABSTRACT

This article focuses on the modelling and analysis of an automatic braking mechanism for low-speed driving scenarios. The study aims to replicate the force exerted by a driver on the brake and accelerator pedals by strategically placing the suitable actuator within the pedal subsystem assembly. The primary objective is to model the pedal pressing mechanism for the braking subsystem and gain insights into driver 's behaviour during traffic congestion, thereby ensuring the effective operation of the automatic braking system. The actuator was modelled using 3D virtual environment, while the car body or dynamics was modelled using SimScape in MATLAB environment, and the simulation performance analysis was employed to evaluate the performance outcomes. It has shown that the mechanism designed mimics the actual manual pedal pressing mechanism of driver's leg where the results show that the actuator managed to produce 150 N to reach speed at 8.5 km/h at 48 mm linear actuator stroke. Therefore, the research findings are anticipated to contribute significantly to the advancement of automatic braking systems, particularly during low speed in road traffic delay, which may help in reducing the fatigue among drivers, enhancing vehicle safety, and providing valuable insights for the development of more reliable and efficient systems within the automotive industry.

1. Introduction

Traffic congestion is a major problem in many urban areas. It can lead to the increase of pollution, fuel consumption, and driver 's fatigue and stress. In recent years, there has been a growing interest in the development of advanced driver assistance systems (ADAS) as surveyed conducted by Schwartz [1] that can help to mitigate the effects of traffic congestion. It is also noted in urban development theory that the geographical features of a city and its transportation networks impact its growth. Traffic congestion is a complex issue that demands a multifaceted approach. This includes reducing the need for travel, promoting alternatives to passenger cars, enhancing public transport, and optimizing infrastructure. These findings by Kozlak and Wach in [2] can guide policymakers at all

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levels of government in crafting effective transportation strategies. In flat places, affordable roads, railways, and canals may be built, allowing certain land uses, such as industry, to spread out. In general, major cities have the same problem with transportation, notably highway traffic congestion. The first objective for any policy-making process to cope with the worsening situation is to determine the economic impact of traffic delays on the whole national economy. Estimates of delay costs also offer a value that may be imposed on road users, which is a very successful and widely used traffic demand control approach as research done by Fattah *et al.,* [3]. The research that conducted by Hasmita *et al.,* [4] show that drivers who drive amid traffic congestion may make more movements by manually pushing the accelerator and stop pedals in order to maintain a safe distance from other cars and pedestrians nearby. Drivers who adopt inappropriate seating positions when dealing with heavy traffic may have bodily fatigues such as achy back, stiff neck, leg discomfort, and uncomfortable shoulders as the study already executed by Niyzar *et al.,* [5].

One promising area of research is the development of actuator-based braking systems. These systems use actuators to apply the brakes automatically, which can help to reduce driver fatigue and improve safety, as mentioned in the previous study [1]. The goal of the given work is to provide a novel approach that, when applied to an electromechanical device, allows for the analysis of its electrodynamics as finding from the analysis by Santo *et al.,* [6]. Besides that, advancement of Advanced Driver Assistance Systems (ADAS) is to automate driving tasks and improve safety and many technologies created to improve ADAS such as Adaptive Cruise Control (ACC) that research done by Sivaji *et al.,* [7]. Within this realm, the focus of this study is the analysis and optimization of an automatic braking system for low-speed driving scenarios in line with research accomplished by Fletcher *et al.,* [8]. ADAS technologies utilize various sensors, cameras, radar, LIDAR, and other components to collect data about the vehicle's surroundings, its own state, and the behavior of other road users as the investigation carried out by Alsuwian *et al.,* [9]. This data is then processed and used to provide feedback to the driver or even perform certain actions autonomously. There is also ACC technology, which has several types of driving modes on the road, such as maintaining speed and acceleration on the road to avoid collisions, according to Miyata's *et al.,* [10] study. In this proposed mechanism, it only uses an actuator as an external device to physically control the brake pedal to replace human foot to press the pedal.

The primary goal is to model the braking system mechanism and gain insights into driver behavior during traffic congestion, ensuring effective operation of the automatic braking system as some of other researchers also demonstrated the automatic emergency braking based on other's vehicle positioning by Wei Yang *et al.,* [11]. Additionally, the study considers the integration of the car's dynamics with the actuator and employs simulation methods to compare results. Optimization based on the car's brake pedal dimensions is also taken into account to enhance driver comfort during the braking process.

In this paper, the finding is about the performance of the actuator for the car to replace a human's foot to work by pressing the pedal. The issue that needs this proposed mechanism to be done is drivers are frequently compelled to repeatedly press the pedals of their vehicles, such as the accelerator or brake, under heavy traffic congestion which can cause severe weariness and fatigue. According to research that done by Gyulyev *et al.*, [12] show that many factors that affect driver's fatigue during the traffic jam. This not only impacts the driver's comfort and well-being, but it also poses major safety dangers on the road.

The actuator must have the best characteristics in order to do work as humans do to press the pedal brake. Electromechanical and electromagnetic actuators are commonly used in a wide range of industrial applications, including brake pedal pressing mechanisms. These actuators rely on the interaction of electrical and mechanical components to provide precise and controlled motion.

Electromechanical actuators can offer accurate force application in the context of a brake pedal, providing consistent and dependable braking performance as demonstrated in research carried out by Qiao *et al.,* [13]. Electromagnetic actuators that were revealed in the research conducted by Sultoni *et al.,* [14] on the other hand, use magnetic fields to create linear or rotational motion, allowing for quick and rapid actuation. Both types of actuators are well-suited for developing effective and efficient brake pedal pressing mechanisms in industrial settings due to their versatility, efficiency, and ability to connect smoothly with control systems.

The position of the actuator may play an important role in giving the optimum performance. As there is also past research that conduct robot arm to press the brake pedal that done by Krishnapuram *et al.,* [15] the concept is used to build to the pedal braking mechanism by using actuator. From the review conducted, there is not much research conducted in addressing low speed control using linear actuator replacing the human foot as what is being proposed and this paper uses different platforms of subsystem models including the 3D virtual mode of pedal subsystem, vehicle dynamic using the system identification and integrated into the Simscape platform in MATLAB.

2. Modelling

The model of the whole system is based on different models of subsystem designed in different environment including the 3D simulation Solidworks environment, where the pedal was designed to be placed in front of the pedal, as shown in Figure 1. This design is assumed to be the best position of the actuator as it has the same angle of the human foot to press the pedal in reality. In addition, full mathematical model of linear actuator was derived in details as part of this research, [16,17].

The Simscape in MATLAB was used to analyze the performance of the integrated subsystem as a complete model. The model of the pedal subsystem was imported from Solidworks to Simscape environment for simulation while the car vehicle dynamic model and motor model were also retrieved to be integrated with the pedal Simscape model. From the linear actuator, the force was measured with the step input reference used with the final value of 10. Figure 2 and Figure 3 below show the model of the actuator in the Simscape platform, which is designed to press the brake pedal. Then, the position of the brake pedal is measured in response to the position of the linear actuator while pressing the brake pedal.

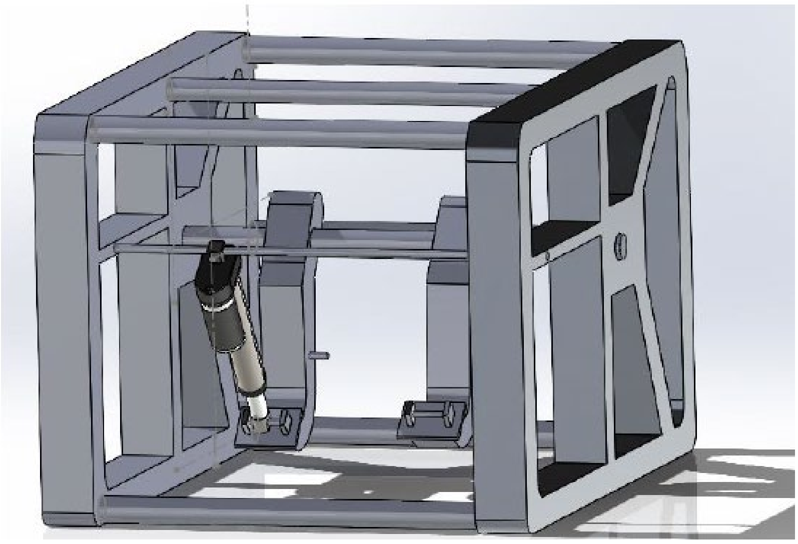

Fig. 1. Illustration of the Actuator and the Brake Pedal Setting

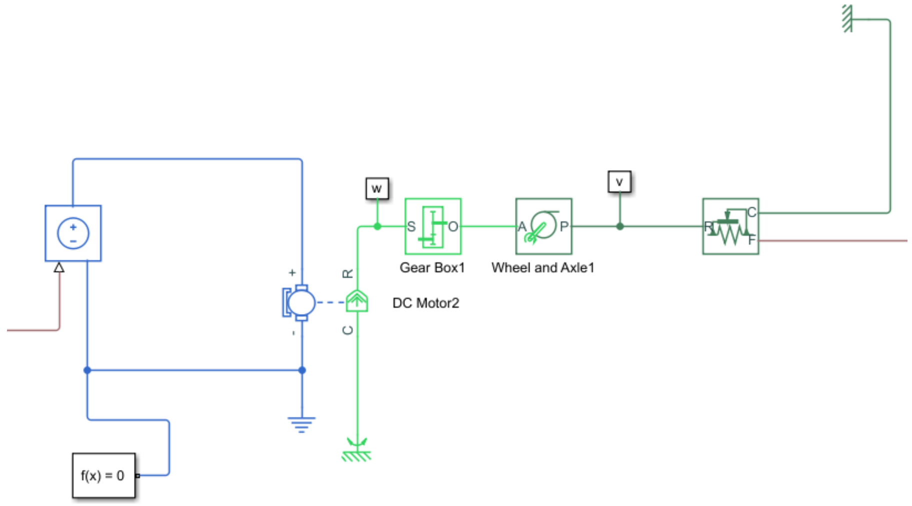

Fig. 2. Linear Actuator Model

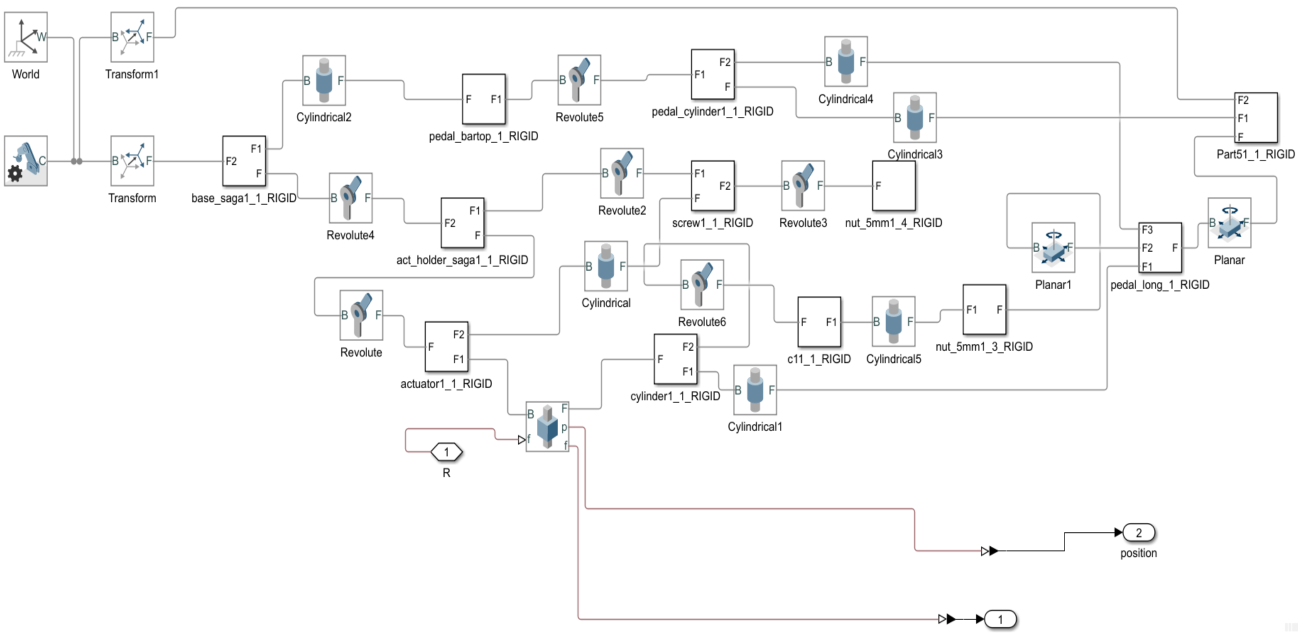

Fig. 3. The Simscape Model of the pedal subsystem

The Simscape model of the linear actuator in Figure 2 was then minimized as one subsystem and integrated with the linear actuator model. The car dynamic model was integrated, and the speed output was measured from the car model. Figure 4 and Figure 5 below show the final setup of the simulation environment with the open loop and closed loop system conditions.

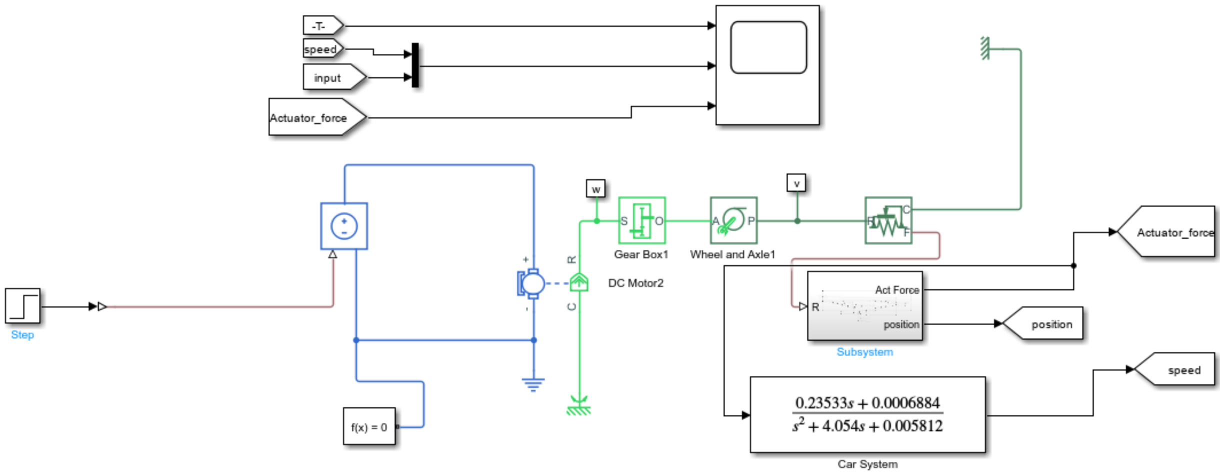

Fig. 4. Open loop Simulation

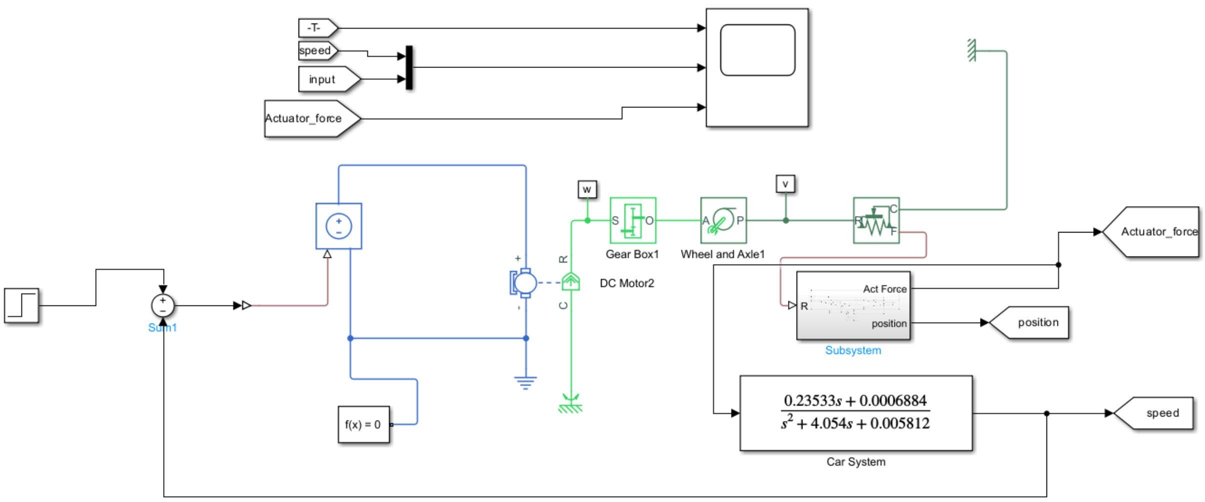

Fig. 5. Closed Loop Simulation

The setup was simulated, and the parameters of the pedal's position and the force of the actuator were measured and similarly the speed of the car was obtained. The open loop and the closed loop system were compared to ensure the best result of the actuator that can represent the overall model pressing mechanism of the pedal subsystem.

3. Simulation Results

3.1 Open Loop System Performance Analysis

Figures 6 to 8 show the outcomes of the interest parameters for the open loop system performance analysis including the position of the pedal, the speed of the car and the actuator's force produced.

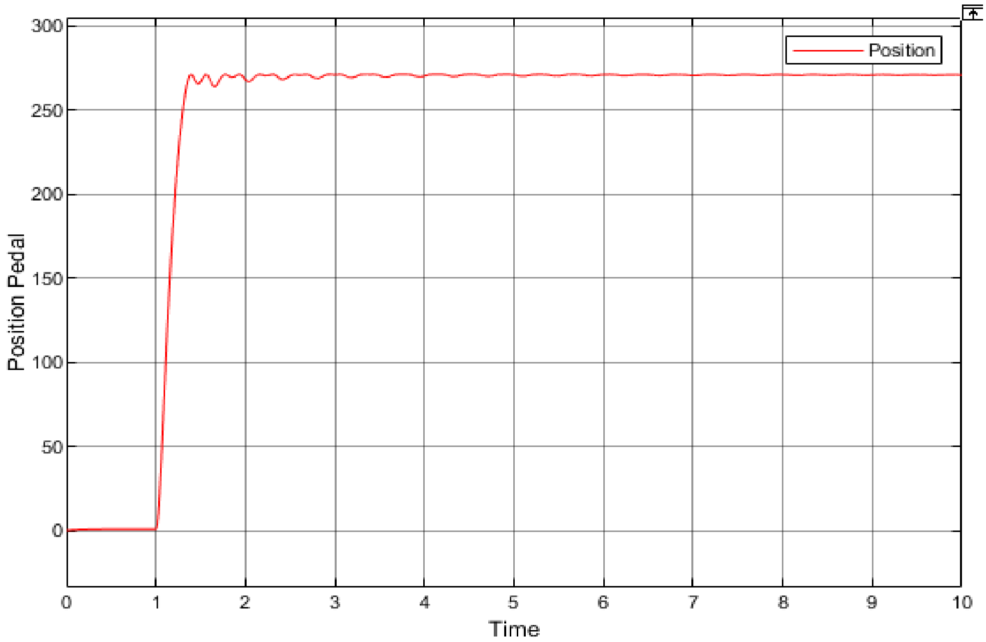

Fig. 6. The pedal's position (mm)

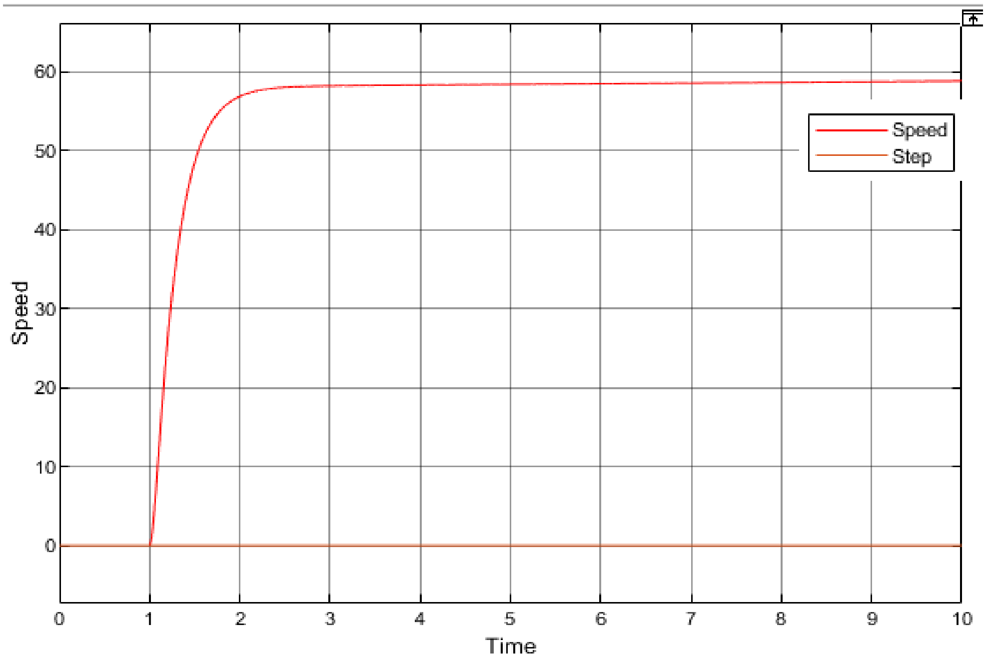

Fig. 7. The speed of the car (km/h)

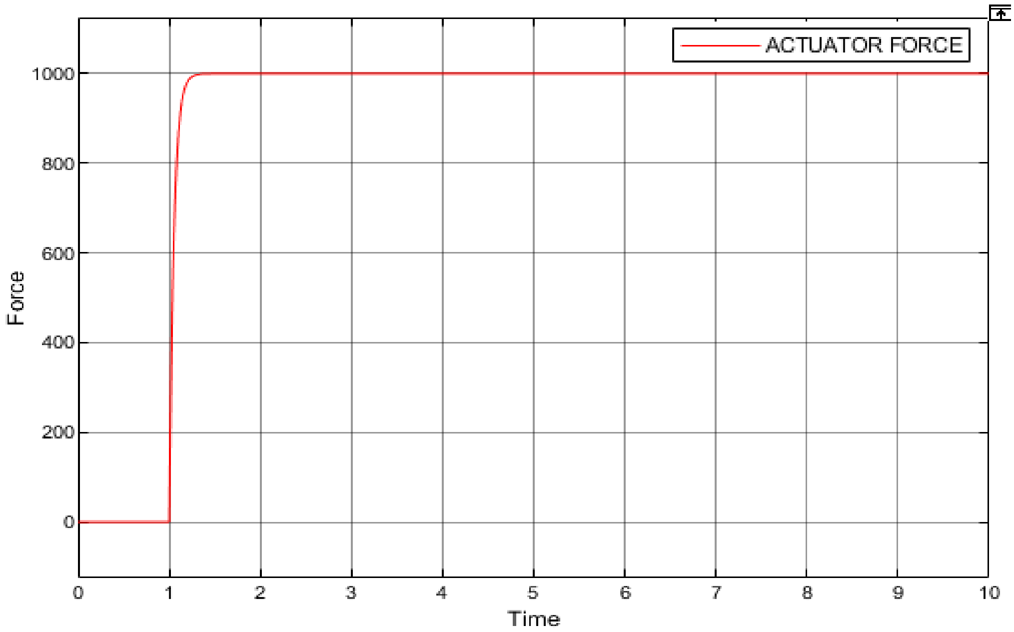

Fig. 8. The actuator 's force (N)

3.2 Closed Loop System Performance Analysis

Figures 9 to 11 show the outcomes of the interest parameters for the closed loop system performance analysis including the position of the pedal, the speed of the car and the actuator's force produced. Table 1 summarize the performance analysis for both open loop and closed loop system.

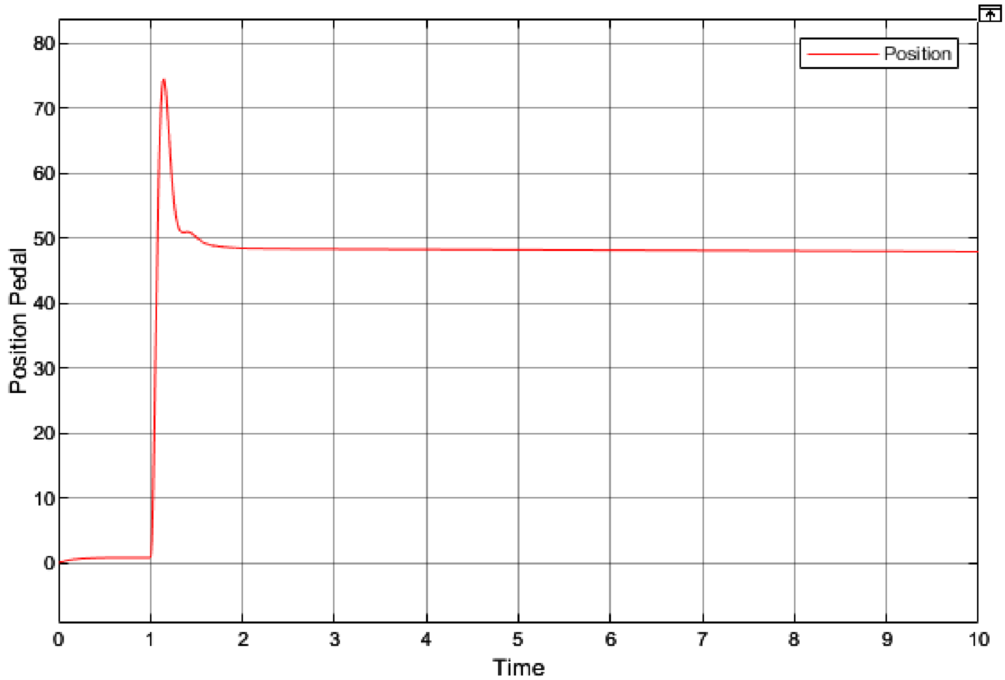

Fig. 9. The pedal's position (mm)

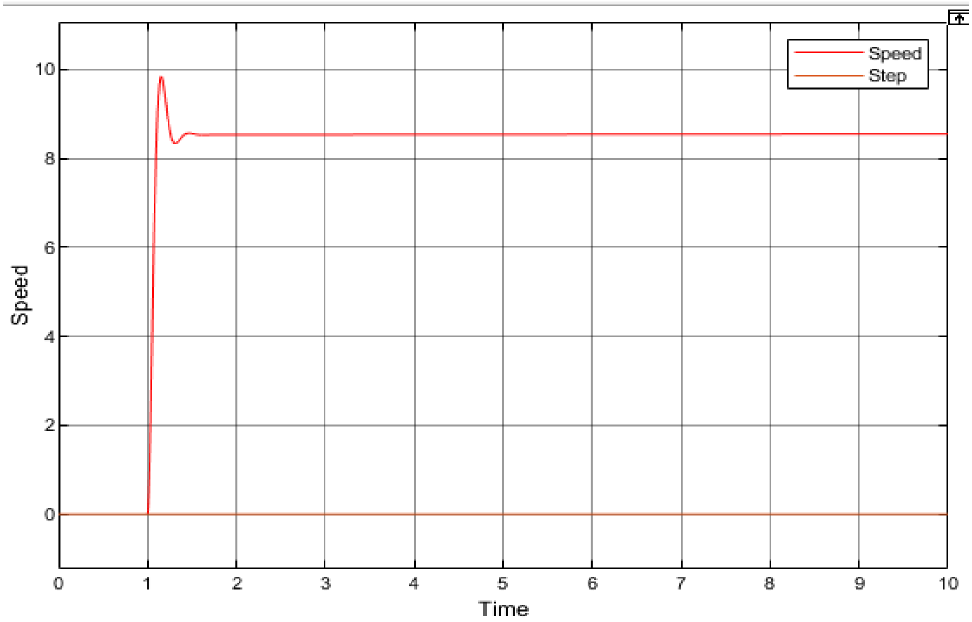

Fig. 10. The speed of the car (km/h)

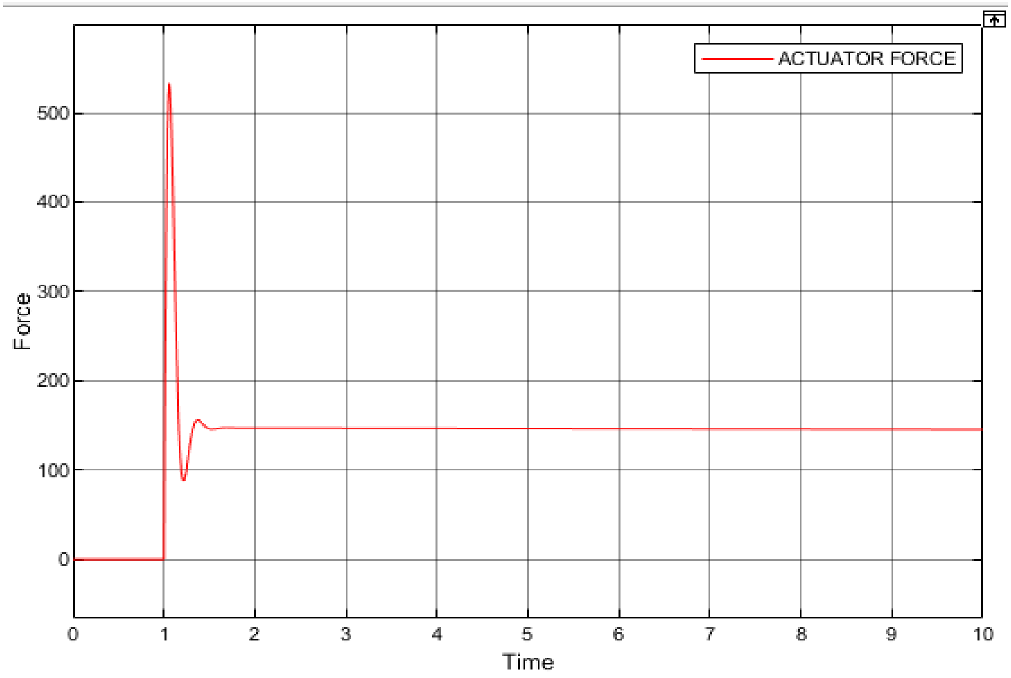

Fig. 11. The actuator's force (N)

Table 1
Performance comparison of both system

	Open Loop System	Closed Loop System
Pedal's Position (mm)	275	48
Speed of the Car (km/h)	58	8.5
Actuator's Force (N)	1000	150

Both systems receive the same input value from the step input with a final value of 10 which sets the car speed to 10 km/h. In the open-loop system performance analysis, the actuator receives a step input with a final value of 10, which means it will apply a constant force or displacement to the brake pedal without any feedback or control. The outputs, which includes the position of the pedal and the force of the actuator, as well as the speed of the car, are not actively measured or adjusted based on the system's response. Therefore, the open-loop system lacks the ability to adapt to changing conditions or disturbances during the braking process.

On the other hand, the closed loop system incorporates the feedback to continuously monitor and adjust the actuator's output based on the measured values of the position of the pedal and force of the actuator, as well as the speed of the car. The closed loop system compares the desired response which is set as the step input with a limit of 10 km/h to the actual response measured by sensors. It was then adjusted the actuator's input based on the error between the desired and actual values, currently using only proportional control algorithm.

As can be seen in the results produced, the closed loop system's feedback mechanism with purely gain controller allows it to continuously track and compensate for any discrepancies between the desired and the actual response. This enables the system to adapt to variations in the vehicle's speed, road conditions, or driver behavior, resulting in better performance of the actuator's position and force. Consequently, the closed loop system is expected to provide better braking performance, increased stability, and improved overall driving experience. Detailed review on the comparison and effect of closed loop and open loop in a system can be seen in review papers by several previous authors [17-21]. In is anticipated that the system will be further improved when a suitable control algorithm is employed within the closed loop environment.

4. Conclusion

In conclusion, the pedal pressing mechanism using linear actuator was successfully modelled, designed and has produced acceptable range of force for reducing the speed of car, which possesses the similar behavior as a human foot. The model of the subsystems was executed on different platforms including the Simscape, 3D virtual environment and transfer function obtained from system identification. From the simulation results, there was a significant correlation seen between the force that is exerted on the brake pedal and the speed of the car. The position of the pedal was measured upon the action of the stroke of the linear actuator receiving the input signal, which mimics the human foot that presses the pedal. The simulation has shown that the mechanism designed mimics the actual manual pedal pressing mechanism of driver’s leg where the linear actuator managed to produce about 150N to reach speed of 8.5 km/h at 48 mm linear actuator stroke. The result shows that the simulation executed from the Simscape environment produces promising and better results of the pedal pressing mechanism of the brake, with the pressing mechanism that can be visualized and future control strategies can further improve the system performance.

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References
[1] Schwartz, Jake S. "Design of an automobile accelerator/brake pedal robot for advanced driver assistance systems." PhD diss., 2017.
[2] Koźlak, Aleksandra, and Dagmara Wach. "Causes of traffic congestion in urban areas. Case of Poland." In *SHS Web of Conferences*, vol. 57, p. 01019. EDP Sciences, 2018.https://doi.org/10.1051/shsconf/20185701019
[3] Fattah, Md Abdul, Syed Riad Morshed, and Abdulla-Al Kafy. "Insights into the socio-economic impacts of traffic congestion in the port and industrial areas of Chittagong city, Bangladesh." *Transportation Engineering* 9 (2022): 100122. https://doi.org/10.1016/j.treng.2022.100122

[4] Hasmita, Lia, and Nur Afinie Binti Radzuan. "The public perception of traffic jam in Kuala Lumpur Malaysia." *Sumatra Journal of Disaster, Geography and Geography Education* 2, no. 2 (2018): 86-90. https://doi.org/10.24036/sjdgge.v2i2.157

[5] Zifruddin, Ahmad Niyzar Ahmad, Salmiah Ahmad, Hazril MD Isa, Muhammad Abdullah, Normaniha Abd Ghani, and Nurul Muthmainnah Mohd Noor. "Parametric Modelling of Pedal Pressing Activities During Road Traffic Delay." *Journal of Modern Mechanical Engineering and Technology* 9 (2022): 1-12. https://doi.org/10.31875/2409-9848.2022.09.1

[6] Santo, A. Espírito, MR A. Calado, and C. M. P. Cabrita. "Dynamic simulation of electromagnetic actuators based on the co-energy map." *The Applied Computational Electromagnetics Society Journal (ACES)* (2010): 1118-1128.

[7] Sivaji, V. V., and M. Sailaja. "Adaptive cruise control systems for vehicle modeling using stop and go manoeuvres." *International Journal of Engineering Research and Applications* 3, no. 4 (2013): 2453-2456.

[8] Fletcher, Ian, B. J. B. Arden, and C. S. Cox. "Automatic braking system control." In *Proceedings of the 2003 IEEE International Symposium on Intelligent Control*, pp. 411-414. IEEE, 2003. https://doi.org/10.1109/ISIC.2003.1254670

[9] Alsuwian, Turki, Rana Basharat Saeed, and Arslan Ahmed Amin. "Autonomous vehicle with emergency braking algorithm based on multi-sensor fusion and super twisting speed controller." *Applied Sciences* 12, no. 17 (2022): 8458. https://doi.org/10.3390/app12178458

[10] Miyata, Shigeharu, Takashi Nakagami, Sei Kobayashi, Tomoji Izumi, Hisayoshi Naito, Akira Yanou, Hitomi Nakamura, and Shin Takehara. "Improvement of adaptive cruise control performance." *EURASIP Journal on Advances in Signal Processing* 2010 (2010): 1-8. https://doi.org/10.1155/2010/295016

[11] Yang, Wei, Jiajun Liu, Kaixia Zhou, Zhiwei Zhang, and Xiaolei Qu. "An automatic emergency braking model considering driver's intention recognition of the front vehicle." *Journal of advanced transportation* 2020 (2020): 1-15. https://doi.org/10.1155/2020/5172305

[12] Gyulyev, Nizami, Oleksii Lobashov, Oleksii Prasolenko, and Igor Bugayov. "Modeling the effect of traffic jam on driver's level of fatigue." In *SHS Web of Conferences*, vol. 67, p. 04005. EDP Sciences, 2019. https://doi.org/10.1051/shsconf/20196704005

[13] Qiao, Guan, Geng Liu, Zhenghong Shi, Yawen Wang, Shangjun Ma, and Teik C. Lim. "A review of electromechanical actuators for More/All Electric aircraft systems." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 232, no. 22 (2018): 4128-4151. https://doi.org/10.1177/0954406217749869

[14] Sultoni, Arif Indro, I. Nyoman Sutantra, and Agus Sigit Pramono. "H∞ Multi-Objective Implementation for Energy Control of Electromagnetic Suspension." *International Review of Mechanical Engineering* 9, no. 6 (2015): 542-547. https://doi.org/10.15866/ireme.v9i6.7125

[15] Krishnapuram, Seetharam, Adithya Kameswara Rao, K. M. Dhivakar, and Mayank Kapur. "Robotic arm for automatic brake testing and control." In *Journal of Physics: Conference Series*, vol. 1831, no. 1, p. 012021. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1831/1/012021

[16] Mike Blundell, Damian Harty, Chapter 6 - Modelling and Assembly of the Full Vehicle,Editor(s): Mike Blundell, Damian Harty,*The Multibody Systems Approach to Vehicle Dynamics (Second Edition)*,Butterworth-Heinemann,2015,Pages 451-533,ISBN 9780080994253. https://doi.org/10.1016/B978-0-08-099425-3.00006-6.

[17] Hazril Md Isa, Salmiah Ahmad, Muhammad Abdullah, Ataur Rahman, NMA Ghani and N.M.M Noor, "Modelling of Pedals Pressing Mechanisms for Low Speed Driving in Road Traffic Delay", IOP Conf. Ser.: Mater. Sci. Eng. 1244 (2033): 012010. https://doi.org/10.1088/1757-899X/1244/1/012010

[18] Robert D. Christ, Robert L. Wernli, Chapter 3 - Design Theory and Standards,Editor(s): Robert D. Christ, Robert L. Wernli,*The ROV Manual (Second Edition)*,Butterworth-Heinemann,2014,Pages 55-92,ISBN 9780080982885. https://doi.org/10.1016/B978-0-08-098288-5.00003-8.

[19] Langhanns, Christine, Harald Ewolds, Stefan Künzell, and Hermann Müller. "Contributions of open-loop and closed-loop control in a continuous tracking task differ depending on attentional demands during practice." *Human Movement Science* 85 (2022): 103001. https://doi.org/10.1016/j.humov.2022.103001

[20] Marchetti, G., Claudio Scali, and Daniel R. Lewin. "Identification and control of open-loop unstable processes by relay methods." *Automatica* 37, no. 12 (2001): 2049-2055 https://doi.org/10.1016/S0005-1098(01)00181-9

[21] East, William, Jérôme Turcotte, Jean-Sébastien Plante, and Guifré Julio. "Experimental assessment of a linear actuator driven by magnetorheological clutches for automotive active suspensions." *Journal of intelligent material systems and structures* 32, no. 9 (2021): 955-970. https://doi.org/10.1177/1045389X21991237

[22] Ma, Raja Noor Farah Azura Raja, Fatin Syafiqhah Mohamad Rusidi, and Nur Amira Syahirah Azmar. "Trends Towards the Demand of Electric Vehicles based on the Distribution of Electric Vehicle Charging Stations in Malaysia." *Journal of Advanced Vehicle System* 15, no. 1 (2024): 1-6.