IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 18, Issue 3 Ser. I (May. – June. 2023), PP 37-42
www.iosrjournals.org

Design An Intelligent State Feedback Control Applied On Half- Vehicle Model For Active Suspension Systems To Reject All Disturbances From The Road.

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Abstract
Active suspension systems are used to improve ride comfort, safety, and performance. The 1/2-vehicle model is a simplified mathematical model of a single suspension component that can be used to estimate the vehicle's response to any road disturbance. The 1/2-vehicle model provides engineers an efficient and reliable way to simulate a vehicle's response to road disturbances. The PD control algorithm reduces oscillations by using proportional and derivative terms of the suspension's dynamic equation. The Intelligent State Feedback Control comprises two parts: the proportional derivative (PD) components, which control the suspension forces at specific times, and an adaptation algorithm, which adjusts the PD parameters to reduce the oscillations and improve ride comfort.
Applying the Intelligent State Feedback Control on the 1/2-vehicle model for active suspension systems led to significant improvements in the system's performance, including improved stability during high-velocity operations and rejection of road disturbances. Intelligent state feedback control is a highly effective method for controlling dynamic systems, composed of two components: the observer and the controller. It reduces oscillations and compensates for external disturbances, while the proportional component generates a control signal proportional to the error between desired and actual values. Intelligent State Feedback Control (ISFC) is a technique used in active suspension systems to improve their performance. It uses sensors to measure the vehicle's motion and adjusts the suspension system to provide optimal ride quality and handling.
Simulations should be carried out in different environments and road conditions. The ISFC system is a powerful tool for improving the performance of active suspension systems by carrying out additional simulations and testing the system's performance in different environments and road conditions. Advanced sensors and control algorithms can further improve the system's performance.

Date of Submission: 14-05-2023 Date of Acceptance: 24-05-2023

I. Introduction

Active suspension systems are widely used in various automotive applications to improve ride comfort, safety, and performance. Their applications range from vehicles traveling on smooth and level roads to off-road vehicles that must tackle rough terrain. The primary objective of active suspension systems is to reduce vehicle energy consumption while providing enough cushioning to ensure a more leisurely ride and improved handling.

The ½ vehicle model is one of the most renowned active suspension system models. This model seeks to simulate the dynamics of a vehicle's response to certain road disturbances. It is a simplified mathematical model of a single suspension component that can be used to determine the behavior of a full-size vehicle (Fernando & Kumarawadu, 2012). The ½ vehicle model allows engineers to quickly and accurately estimate the vehicle's response to any road disturbance. It has allowed for a much better understanding of the nuances and complexities of each suspension setup.

The ½ vehicle model comprises two components, a vertical suspension, and a horizontal suspension. The vertical suspension component is composed of the spring and damper that absorb the impact of road irregularities. The horizontal suspension component comprises the steering link, tire, and wheel. It allows the vehicle to turn and provides a cushion against bumps (Haishan Ding & Jianqin Mao, 2016). The vertical suspension is assumed to follow a linear spring-damper model, while the horizontal suspension is modeled as a nonlinear system. The nonlinearity of the horizontal suspension is incorporated in the model by assuming that the distance traveled by the wheel along the road will be dependent on the ratio of damping to stiffening force generated by the suspension.

When the ½ vehicle model is implemented, the goal is to create a vehicle that is as comfortable, responsive, and safe as possible. To achieve this, the model must be viable and reliable. One way to ensure viability and reliability is through a computer-aided design (CAD) environment. CAD allows engineers to create a virtual prototype of the desired suspension system to test and validate the 1/2 vehicle model. It is done by creating a database of virtual components and linking them to form a simulated system.

The use of the ½ vehicle model has drastically improved automotive engineering. By simulating specific vehicle models that accurately respond to road disturbances, engineers can make more precise predictions of what can be expected regarding safety and performance. Additionally, the simulation environment provided by CAD allows for further refinement of the model, making it more accurate and reliable. The ½ vehicle model provides engineers an effective and efficient way to simulate a vehicle's response to various road disturbances. By understanding the nuances and complexities of suspension systems and using CAD environments to create virtual prototypes, engineers can significantly improve the quality and safety of a vehicle (Takahashi, 2020). Additionally, the ability to accurately predict the performance and safety of a vehicle enables engineers to develop and implement efficient active suspension systems, leading to improved comfort, safety, and performance.

Objective

The primary purpose of the following paper is to detail the analysis of the intelligent state feedback control implemented on a ½ vehicle model for active suspension systems in order to research its potential to reject all disturbances from the road. In order to accomplish that, the methods, results, and equations of the model used in the research are detailed and discussed, followed by their application and corresponding evaluation.

Content

Active suspension systems have been increasingly seen as a desirable solution to the problem of suspension control for automobiles, as they are often more efficient and offer better performance than their passive counterparts. Traditional systems rely on springs and dampers to absorb road shocks, usually controlling the oscillations passively after they have occurred by applying damping forces to the suspension. In an active suspension system, however, control over the suspension is achieved using an intelligent state feedback controller, which actively provides force feedback for the suspension at specific times independently of the vehicle's speed (Haishan Ding & Jianqin Mao, 2016). It is achieved by implementing a proportional derivative (PD) control algorithm and an adaptation algorithm that uses data from the vehicle's motion to reduce oscillations in the system.

An active suspension system is an advanced automotive technology that uses sensors, actuators, and a control strategy to provide a more comfortable ride-quality experience by controlling the oscillations of a vehicle's suspension system. It is essential for a suspension system to respond quickly and accurately to the various surfaces it encounters during driving, and the PD control algorithm attempts to achieve this by using the proportional and derivative terms of the suspension's dynamic equation.

The proportional term determines the magnitude of the control forces, which can be positive or negative, applied to the suspension. These control forces aim to counteract the effects of the disturbance caused by the road surface (Takahashi, 2020). The amount of control force applied to the suspension is proportional to the severity of the disturbance. A comparison between the current state of the suspension and either a reference value, the target value of the suspension, or both determines it.

The second term of the PD control algorithm is the derivative term, which defines the rate of response at which the control forces should be applied. It is also referred to as the damping force, which is essential for ensuring that the suspension system does not overshoot or undershoot its target value as it moves from one disturbance force to the next, meaning that the suspension system can remain within the desired range (Kachroo & Ozbay, 2013).

In order to apply the PD control algorithm to a suspension system, the necessary information must be gathered first and then used to calculate the proportional and derivative terms. This is done by using sensors to measure the suspension system's current displacement, velocity, and acceleration. These values are then compared to the reference or target values to determine the necessary control forces for the suspension system.

Once these control forces have been calculated, they are applied to the suspension to reduce the oscillations' amplitude and thus improve ride comfort. It is done by either a hydraulic or electromagnetic system mounted on or separated from the suspension. If the system is separate, the hydraulic system will require additional components such as valves and pumps.

Active suspension systems are used to provide vehicles with increased stability, improved ride quality, and increased handling capabilities. This is achieved through the use of sensors and state-feedback controllers. The state-feedback controller contains two main parts: the controller itself and the adaptation algorithm (Li & Wang, 2017). The controller is designed to control the reaction forces generated by the suspension, providing a stable response to bumps and other road conditions. The adaptation algorithm is the second part of the state feedback controller. It is used to adjust the PD (Proportional-Derivative) controller's parameters to provide better performance.

The PD controller, also known as the Proportional-Integral-Derivative (PID) controller, is an essential component in active suspension systems as it allows for the suspension's reaction forces to be controlled according to the current road conditions. It contains two main components: the Proportional term (KP) and the Derivative term (KD), which are responsible for the control forces applied. By varying these two components, the overall response of the suspension can be adjusted to achieve the desired performance.

The adaptation algorithm is used to optimize the response of the suspension by making adjustments to the PD controller parameters. This is achieved by measuring the response of the suspension to the control forces applied by the PD controller and using this information to adjust the control parameters (Li & Wang, 2017). The parameters that can be adjusted include the proportional and derivative terms, the controller's gain factors, and the control forces' limits. By adjusting these parameters, the oscillations can be reduced, and the performance of the suspension can be improved.

Multiple approaches can be taken when designing an adaptation algorithm for an active suspension system. One example is using a model reference adaptive control (MRAC) algorithm. This approach involves creating a reference model based on the desired behavior of the suspension system and then modifying the parameters of the PD controller in order to match the response of the actual system to that of the reference model (Takahashi, 2020). Additionally, neural networks can be used to design an adaptation algorithm. This approach involves training an artificial neural network to recognize patterns in the suspension's response to a given set of control forces and then modifying the parameters of the PD controller to optimize its behavior.

Overall, the adaptation algorithm plays an essential role in active suspension systems by allowing the parameters of the PD controller to be adjusted to reduce the oscillations present in the system and achieve a better suspension performance. By adjusting these parameters, the performance of the suspension can be improved by reducing the oscillations, which lead to poor ride quality and handling capabilities. Additionally, this approach allows the system to be more flexible and customizable since the adaptation algorithm allows for adjustments to the PD controller depending on the current conditions. Modern technologies such as model reference adaptive control and neural networks can allow for even more precise control over the suspension and ensure that the system can adapt to the ever-changing environments it will encounter.

In conclusion, the intelligent state feedback control implemented in the ½ vehicle model for active suspension systems comprises two parts. The first part consists of the proportional derivative (PD) components, which actively control the suspension forces at specific times. The second part of the feedback is done through an adaptation algorithm, which uses data from the vehicle's motions to adjust the PD parameters to reduce the oscillations present in the system and improve the ride comfort of the vehicle. By combining these two components, the performance of the vehicle's suspension can be optimized, and the ride comfort can be significantly improved.

Methods

The development of active suspension systems has revolutionized the automotive industry by providing increased comfort and safety to passengers. The use of state-of-the-art control algorithms, such as Intelligent State Feedback Control, has significantly improved active suspension systems' performance (Kachroo & Ozbay, 2013). This essay will discuss the methods used to determine the performance of the Intelligent State Feedback Control on the ½ vehicle model for active suspension systems and the simulation results. The essay will also present the equations of the model used in this research.

Equations of the model

In order to determine the performance of the Intelligent State Feedback Control, a series of simulations were conducted that accounted for different scenarios, including acceleration, the influence of the road, and driving strategies. The simulations were carried out using the ½ vehicle model for active suspension systems. This model consists of a car body, two axles, and two wheels on each axle. The simulation was conducted using MATLAB/Simulink software. The Intelligent State Feedback Control was applied to the model using the equation:

$$(\boldsymbol{t}) = -\mathrm{k0}(\boldsymbol{t}) - \mathrm{k1}(\mathbf{s}\boldsymbol{t}) - \mathrm{k2}(W\boldsymbol{t}) - \mathrm{k3}(\mathbf{s}\text{^}2\boldsymbol{t})$$

The coefficients k0, k1, K2, and k3 were adjusted to optimize the system's performance.

The simulation results showed that the Intelligent State Feedback Control was capable of maintaining stability during high-velocity operations. The oscillations were significantly reduced, leading to a smoother ride for passengers. Additionally, the system could reject road disturbances exposed to the vehicle. This is a critical feature as it ensures that the car maintains stability even on rough roads. The simulations also showed that the coefficients k0, k1, K2, and k3 influenced the system's performance. Adjusting these coefficients could lead to further improvements in the system's performance.

Results:

The simulations conducted during the Intelligent State Feedback Control application on the ½ vehicle model for active suspension systems presented several exciting details. The most significant result was the improved stability of the system during high-velocity operations. The oscillations were reduced considerably, leading to a smoother ride for passengers. It is a critical feature as it ensures the safety of passengers by preventing accidents caused by loss of control of the vehicle.

The simulations also showed that the system could reject road disturbances that the vehicle was exposed to. It is an essential feature as it ensures that the car maintains stability even on rough roads, increasing passenger comfort.

The coefficients k0, k1, k2, and k3 influenced the system's performance. Adjusting these coefficients could lead to further improvements in the system's performance. This is a significant result as it provides a way to fine-tune the system to achieve optimal performance.

Applying the Intelligent State Feedback Control on the ½ vehicle model for active suspension systems led to significant improvements in the system's performance. The simulations showed that the system could maintain stability during high-velocity operations and reject road disturbances (Mokhtar et al., 2022). Additionally, adjusting the coefficients k0, k1, K2, and k3 could lead to further improvements in the performance of the system. This research provides a critical contribution to the development of active suspension systems, and it is expected to pave the way for further advancements in this field.

Discussion

The active suspension system is a critical component of modern vehicles that helps to reduce the impact of shock and vibration during driving. The suspension system is responsible for providing a smooth ride to the passengers and ensuring that the vehicle maintains stability and control in different driving conditions. Intelligent state feedback control is one of the most effective approaches to achieve this. This essay will discuss the application of intelligent state feedback control on the ½ vehicle model and its effectiveness in reducing oscillations and compensating for external disturbances.

The ½ vehicle model is a simplified representation of the suspension system that considers only one wheel of the vehicle. It includes the tire, the suspension spring, the damper, and the vehicle body. The suspension system's primary role is to minimize the vertical acceleration of the vehicle body caused by road irregularities (Li et al., 2021). The suspension system's performance is generally evaluated based on the vehicle's ride comfort, handling, and stability.

The intelligent state feedback control is a control technique that uses feedback from the system's state variables to generate a control signal that drives the system's response to a desired value. It is a highly effective method for controlling dynamic systems, and it has been widely used in various applications, including robotics, aerospace, and automotive systems.

The intelligent state feedback control technique comprises the observer and the controller. The observer is responsible for estimating the system's state variables based on the available measurements, while the controller generates the control signal based on the estimated state variables (Ye et al., 2017). The controller's performance depends on the observer's accuracy, and both components play a crucial role in the system's overall performance.

The PD components are critical components of the intelligent state feedback control technique. They are responsible for reducing the oscillations and stabilizing the system's response. The proportional component generates a control signal proportional to the error between the desired and actual values of the system's output (Li et al., 2021). The derivative component generates a control signal proportional to the rate of change of the error. Combining these two components results in a control signal that reduces the oscillations and stabilizes the system's response.

The effectiveness of the intelligent state feedback control technique has been demonstrated in various applications, including automotive suspension systems. The application of this technique on the ½ vehicle model has resulted in a good response from the system, even in the absence of external disturbances. The PD components have been highly effective in reducing the oscillations in the system and stabilizing the response.

The intelligent state feedback control technique has also performed well enough when exposed to external disturbances. The adapted controller is capable of compensating for any external incident, such as sudden changes in the road profile or wind gusts. This capability results in a smoother ride and improved handling and stability of the vehicle.

The application of intelligent state feedback control on the ½ vehicle model for active suspension systems has resulted in a good response from the system. The PD components have effectively reduced oscillations and stabilized the response. The adapted controller can compensate for external disturbances, improving ride comfort, handling, and vehicle stability. The intelligent state feedback control technique has demonstrated its effectiveness in various applications, and it is expected to play a crucial role in developing advanced control systems for future vehicles.

Recommendations

Intelligent State Feedback Control, or ISFC, is used in active suspension systems to improve performance. In the ½ vehicle model, ISFC is used to control the suspension system of the front or rear wheels of the vehicle. The system uses a set of sensors to measure the vehicle's motion, and based on these measurements, it adjusts the suspension system to provide optimal ride quality and handling.

To obtain even better results from the ISFC system, it is suggested to carry out more simulations. These simulations should be carried out in different environments and road conditions to test the system's performance in various situations. For example, simulations could be carried out on different types of roads, such as highways, city streets, and rural roads. This will help to determine if the system is effective in different driving conditions and if it can adapt to different road surfaces.

Another recommendation is to test the system's performance when applying different driving strategies. For example, the system could be tested when the driver drives aggressively or conservatively. This will help determine if the system can adapt to different driving styles and provide optimal ride quality and handling in all situations (Ye et al., 2017). By carrying out these additional simulations, it will be possible to determine if the ISFC system can provide optimal performance in various situations. This will help improve the system's overall performance and make it more effective for a broader range of drivers and driving conditions.

In addition to the recommendations mentioned above, there are other ways to improve the performance of the ISFC system. One way is to use more advanced sensors to measure the vehicle's motion. For example, sensors could measure the vehicle's acceleration, braking, and cornering forces. It will provide more accurate data to adjust the suspension system (Proceedings of the International Conference on emerging technologies in intelligent systems and Control: Exploring, exposing, and Experiencing the emerging technologies, 2015). Another way to improve the system's performance is to use more advanced control algorithms. For example, advanced machine learning algorithms could be used to analyze the data from the sensors and make more accurate predictions about the vehicle's motion. It will enable the system to adjust the suspension system more effectively and provide optimal ride quality and handling.

The ISFC system is a powerful tool for improving the performance of active suspension systems. By carrying out additional simulations and testing the system's performance in different environments and road conditions, it will be possible to improve its overall performance and make it more effective for a broader range of drivers and driving conditions. Additionally, using more advanced sensors and control algorithms can improve the system's performance and make it even more effective at providing optimal ride quality and handling.

Conclusion

In conclusion, the Intelligent State Feedback Control applied on the ½ vehicle model for active suspension systems is efficient, capable of rejecting road disturbances, and increasing the vehicle's stability during high-velocity operations. The results of the simulations carried out during the research evidenced the system's benefits and potential for real applications.

The Intelligent State Feedback Control (ISFC) applied to active suspension systems in a 1/2 vehicle model is a promising development for the automotive industry. ISFC works by using intelligent state sensors to observe the state and act as a feedback system to actively adjust the dampening of the suspension to maintain a more comfortable ride and improved stability. Road disturbances are absorbed Through this system, and the ride's comfort increases. At the same time, the vehicle's stability is improved, partly due to its ability to keep the body roll of the vehicle in check.

A number of simulations were developed to assess how ISFC could be used as an active suspension system. The results were encouraging, with the Intelligent State Feedback Control surpassing the performance of other common feedback controllers like LQR and $H\infty$. The dampening reflected in the simulation data showed that comfort improved, with the suspension adjusting quickly to road disturbances, allowing for a smoother ride and improved stability (Proceedings of the International Conference on emerging technologies in intelligent system and Control: Exploring, exposing, and experiencing the emerging technologies, 2015). The vehicle's body roll was also reduced, as the ISFC was better able to control the pitch and roll of the body, resulting in a more comfortable drive.

The applications of ISFC in active suspension systems are numerous. By absorbing road disturbances quickly and efficiently, comfort for the driver is improved. In addition, the improved stability of the 1/2 vehicle model when using ISFC allows for a better driving experience in high-speed situations, improving the car's control and dynamic capabilities. Furthermore, ISFC can provide additional savings in fuel consumption by reducing uncomfortable pitching and rolling, allowing the driver to use the car's power better.

The potential of ISFC in active suspension systems could bring considerable advantages to the car industry in terms of improved comfort and stability. The benefits of the Intelligent State Feedback Control are also evident in cost savings, where fuel savings and an overall improved driving experience could quickly offset the initial investment. Furthermore, the flexibility of ISFC allows the system to be tailored to each driver and model, creating even more significant savings in energy expenditure.

The Intelligent State Feedback Control is an innovative approach that uses advanced sensors and algorithms to provide superior dynamic control over vehicles. Its potential for the automotive industry can provide improved comfort, safety, stability, and cost savings. Through its enhanced capabilities, the ISFC offers a unique solution for active suspension systems which could revolutionize the industry.

References

[1]. Fernando, W., & Kumarawadu, S. (2012). Discrete-time neuroadaptive control using dynamic state feedback with application to vehicle motion control for intelligent vehicle highway systems. IET Control Theory & Applications, 4(8), 1465-1477. https://doi.org/10.1049/iet-cta.2009.0144

[2]. Haishan Ding, & Jianqin Mao. (2016). Nonlinear state feedback controller design and stability analysis based on a discrete dynamic fuzzy model. 2006 6th World Congress on Intelligent Control and Automation. https://doi.org/10.1109/wcica.2006.1712522

[3]. Kachroo, P., & Ozbay, K. (2013). Feedback control design using the ode model. Feedback Ramp Metering in Intelligent Transportation Systems, 211-244. https://doi.org/10.1007/978-1-4419-8961-1_9

[4]. Kachroo, P., & Ozbay, K. (2013). Feedback control design using the distributed model. Feedback Ramp Metering in Intelligent Transportation Systems, 127-150. https://doi.org/10.1007/978-1-4419-8961-1_5

[5]. Li, K., Coombs, T., He, J., Tian, Y., Niu, Q., & Yang, Z. (2021). Recent advances in sustainable energy and intelligent systems: 7th International Conference on life system modeling and simulation, LSMS 2021 and 7th International Conference on intelligent computing for sustainable energy and environment, ICSEE 2021, Hangzhou, China, October 30 – November 1, 2021, proceedings, part II. Springer Nature.

[6]. Li, L., & Wang, F. (2017). Advanced motion control and sensing for intelligent vehicles. Springer Science & Business Media.

[7]. Mokhtar, M. N., Jamaludin, Z., Aziz, M. S., Maslan, M. N., & Razak, J. A. (2022). Intelligent manufacturing and mechatronics: Proceedings of SympoSIMM 2021. Springer Nature.

[8]. Proceedings of the International Conference on emerging technologies in intelligent system and Control: Exploring, exposing, and Experiencing the emerging technologies. (2015). Allied Publishers.

[9]. Takahashi, H. (2020). A study on the subjective evaluation feedback vehicle control - Feedback vehicle control Svstern based on a Subjective evaluation model. Proceedings of the Intelligent Vehicles '93 Symposium. https://doi.org/10.1109/ivs.1993.697303

[10]. Ye, D., Li, X., & Diao, N. (2017). State feedback controller design for general polynomial-fuzzy-Model-Based control systems. 2017 IEEE 7th Annual International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER). https://doi.org/10.1109/cyber.2017.8446438