ACTIVE SUSPENSION SYSTEM AND CONTROL SYSTEM FOR ACTIVE SUSPENSION

by

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CERTIFICATION

This is to certify that Yusuf Abdulmummin Ayomiku (EES/18/19/0585) carried out this project under the supervision of Dr. Ayobami Layeni.

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Dr. Ayobami Layeni   Date

Project Supervisor

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Dr.   Date

Ag. Head of Department

DEDICATION

I would like to dedicate this project to God Almighty and my family.

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I would like to express my sincere gratitude to all those who have contributed to the successful completion of my first degree in Mechanical Engineering. I would like to acknowledge the following individuals and organizations for their support, guidance, and encouragement throughout this endeavor:

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ABSTRACT

CHAPTER ONE

1.0 Introduction

1.1 Background of the study

Active suspension refers to a technology in vehicles that actively adjusts the individual suspension components to enhance ride quality and performance. Unlike conventional passive suspension systems, which rely on fixed dampers and springs, active suspensions utilize sensors, actuators, and a control system to continuously monitor and adapt the suspension settings in real-time.

The primary objective of active suspension is to improve comfort, handling, and stability by mitigating the effects of road irregularities and vehicle dynamics. By analyzing data from sensors, such as accelerometers, wheel speed sensors, and ride height sensors, the control system can detect and respond to changes in external forces, vehicle motion, and driver inputs.

The active suspension control system makes adjustments to the dampers, often referred to as active dampers or electronic dampers, to optimize suspension response. These adjustments can be made within milliseconds and can vary the damping characteristics based on the road conditions and driving situation.

Active suspension systems can provide several benefits, including:

1. Improved ride comfort: The active dampers can quickly and precisely adjust to absorb bumps and vibrations, resulting in a smoother and more comfortable ride for passengers.
2. Enhanced handling and stability: By actively controlling the suspension, active systems can reduce body roll during cornering and minimize pitch and dive during acceleration and braking, leading to improved handling and stability.
3. Adaptability to different driving conditions: Active suspension systems can adjust their settings based on road conditions, such as rough surfaces, potholes, or uneven terrains. They can also adapt to changing loads or weight distribution within the vehicle.

4. Customizable modes: Some active suspension systems offer multiple modes, such as comfort, sport, or off-road, allowing drivers to select the desired suspension characteristics according to their preferences or driving conditions.

However, it's important to note that active suspension systems can be more complex and expensive compared to passive systems. They require additional components, such as sensors, actuators, and control units, which increase the overall cost and maintenance requirements of the vehicle.

Despite the added complexity, active suspension technology continues to advance, and it is increasingly being adopted in high-end luxury vehicles as well as performance-oriented cars to offer superior ride quality, improved handling, and enhanced overall driving experience.

1.2 Aim and Objectives

1.2.1 Aim

The aim of the project is to develop an active suspension system and control system for active suspension

1.2.2 Objectives

I. To investigate the active suspension technology and how they differ from traditional passive suspension systems. Evaluate the various components, sensors, and actuators involved in active suspensions.

II. To conduct a thorough performance analysis of active suspension systems under different road conditions and driving scenarios. Evaluate their ability to improve ride comfort, handling, stability, and vehicle dynamics compared to conventional passive suspension systems

III. To develop advanced control algorithms for active suspension systems to optimize their response in real-time.

IV. To design an accurate mathematical models of the active suspension system and validate them through computer simulations.

V. To conduct comparative studies between active suspension systems and other advanced suspension technologies, such as semi-active and adaptive suspensions, to identify the advantages and limitations of each approach.

VI. To explore methods for optimizing the active suspension system's performance in terms of ride comfort, handling, and energy efficiency while considering constraints like power consumption and cost.

1.3 Significance

The findings of this study will contribute to advancements in vehicle performance, ride comfort, safety, energy efficiency, and integration with emerging automotive technologies. It has the potential to influence the design and development of future vehicle suspensions, leading to safer, more comfortable, and more efficient transportation solutions.

1.4 Scope of Study

The scope of this study is limited to the active suspension systems and control systems for active suspension involves a systematic approach to investigate, analyze, and validate the performance and effectiveness of these systems.

1.7 Organization of the Study

This study is organized into five chapters. Chapter 1 provides an introduction to the study, including the background, objectives, significance, scope, and organization. Chapter 2 provides a comprehensive literature review of previous studies related to active suspension technology, control strategies, system modeling, performance evaluation, and experimental validation. Chapter 3 describes the experimental methodology used in the study, including the mathematical model, control system design. Chapter 4 presents the results and discussion of the findings. Chapter 5 summarizes the conclusions of the study and provides recommendations for future research.

CHAPTER TWO

2.0 Literature Review

2.1 Suspension system

A suspension system acts as a bridge between the occupants of a vehicle and the road (Youness, and Lobusov, 2019). It has two major functionalities, which are: 1) Isolating the vehicle body and passengers from external disturbances coming from the road, it always relates to riding quality. 2) Maintaining a firm contact between the road and the tires to provide guidance along the track (Cao et al, 2008). Automotive suspension systems are usually classified as passive, semi-active and active suspension systems. The properties of spring and damper in passive suspension determine the dynamic behavior of vehicle, the semi-active suspension uses a variable damper, while in active suspension system, which was first introduced in early 1950's, electronic control systems supervise the operation of the suspension elements (Kunya AB, Ata, 2015). Control approaches for suspension systems are Linear Quadratic Regulator (LQR), Linear Quadratic Gaussian (LQG), Adaptive Sliding Control (ASC), Fuzzy Logic (FL) and Neural Network (NN) methods. Active suspension control systems are typical example of distributed embedded control architectures (Gaid, 2004); many input and output signals should be transmitted via network to a central controller to supervise and control the suspension system.

Active suspension system has a hydraulic actuator in addition to the passive elements. The actuators are used to generate supportive forces that contribute in isolating the body of vehicle from road disturbances (Youness and Lobusov 2019). Fig. 1 describes basic components of active suspension. Fig. 2 shows simple block diagram to explain how the active suspension can achieve better performance. In this type of suspension, Darus and Sam (2008) opined that the controller can modify the system dynamics by activating the actuators. Active suspension systems have the ability to store, dissipate and introduce energy to the system (Canale et al 2006).

According to Kumar and Vijayarangan (2006), During the process of designing a vehicle suspension system the performance parameters that should be taken into consideration are: ride comfort (acceleration sensed by passengers), body motion (bounce), road handling(the contact forces of tires and the road surface), and suspension travel(the displacement between a sprung mass and an unsprung mass. According to Ikenaga(2000),fully active suspension systems are generally in demand of power, Passive suspension systems do not allow for independent control of heave, pitch, or roll motions and are unable to provide reduced sprung mass motions at frequencies above or below the wheel frequency modes. Passive suspensions need suspending more spring loads off the wheels in an effort to increase performance, or the mechanical suspension system's comprehensive redesign. Vehicle handling and passenger comfort are two desired goals that a passive suspension system (PSS) is design to maintain. To create a trade-off between two goals that are in opposition to one another is a design problem. In the face of significant changes in the state of the roads, the PSS cannot adjust itself. However, this can be achieved by using an active suspension system (ASS) to regulate a vehicle's vertical acceleration (Fateh and Alavi, 2009). It consists of an actuator that produces force that is positioned between the sprung and unsprung masses.

According to Chen et al. (2017) the active suspension system is generally divided into two types, namely electromagnetic active suspension and hydraulic active suspension. Active suspension is generally considered as a linear system in control design and performance optimization during research process (Lemoset et al. 2013) though Vaijayanti et al. (2014) disclose that the vehicle suspension system is a typical non-linear system that exhibits complex dynamical behaviors, which can result in an unacceptable detrimental effect on drivers and passengers.

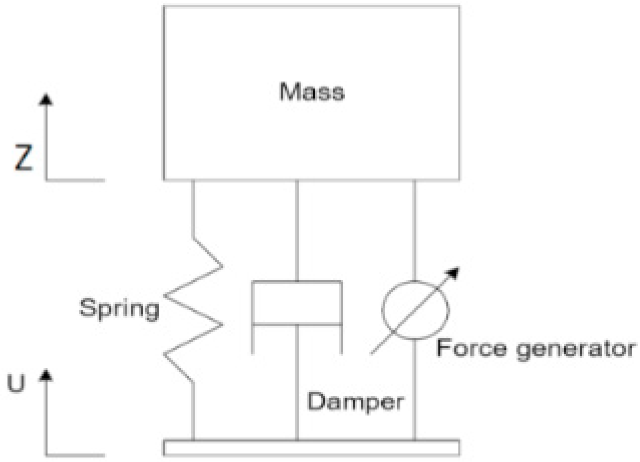

Figure 1: Active suspension component

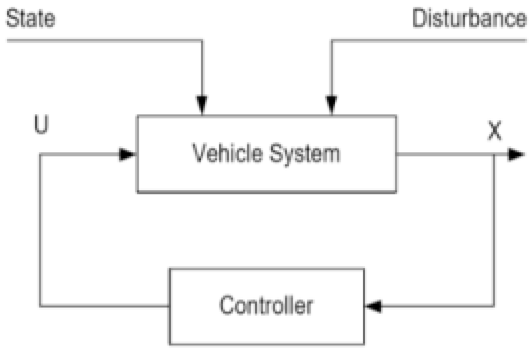

Figure 2: Active suspension control system

Youness and Lobusov (2019) conducted a simulation of two cases of control for a full model car active suspension system. The first case is a control system without network, while the second is a networked control system. In the first approach, there was a comparison between two control methods (PID and LQR) for active suspension systems. Results shown that PID is better than LQR when the goal is to control the suspension travel of the car, while controlling other parameter of the system is more available using LQR and depends on complexity of the reference index used. The second case is a networked control for active suspension system using a proposed model of CAN network in Matlab to transfer the readings values of sensors and actuators to/from a controller; the control method inside the controller is either PID or LQR. The results show that LQR method has better performance than PID when the speed of network is low.

Yu et al. (2006) conducted a study on a magnetorheological (MR) Semi-active Suspension System and its Road Testing. MR dampers are used to replace the passive ones of the front half-car. A quarter-car fuzzy intelligent controller is employed to control the two MR independent suspension systems, respectively. The test results of the performance of the MR suspension system by road testing indicate that the vibration of the vehicle body and unsprung mass are both reduced significantly. Yu et al. (2006) suggest that Semi-active suspension systems offer both the reliability of the passive systems and the versatility and high performance of active control systems with only a little power demand.

Eski and Yıldırım (2009) Study the Vibration control of vehicle active suspension system using a new robust neural network control system, from the simulation results, using the associated control system with robust feedback controller and neural network controller high absolute road profile tracking performance can be achieved for random road roughness. It confirms the effectiveness and robustness of the proposed RNN control system. The performance of the RNN control system is better than standard PID controller.

Canale et al (2006) introduce the design and analysis of a control strategy, for semi-active suspensions in road vehicles, based on Model Predictive Control (MPC) strategies. Simulation results indicate that the approach allows to reach good performance levels in terms of car comfort by reduction of the RMS values of the sprung mass accelerations and a significant attenuation of their extremal values. Moreover also the vehicle handling characteristics are slightly improved as witnessed by the reduction of the RMS values of the forces dynamically exchanged between tire and road. The proposed suspension control strategy appears also feasible from a practical point of view as computational complexity related to the MPC formulation can be overcome by using a suitable “fast” MPC implementation technique.

Van der Sande et al. (2013) considers the control of a novel high bandwidth electromagnetic active suspension system for a quarter car model in both simulations and experiments. They discovered that by changing weighting filters different controllers can be designed, emphasizing either comfort or handling. With the high bandwidth of the actuator comfort can be improved by 40% over the passive BMW whilst keeping suspension travel within the same limits. With a different controller, handling can be improved up to 30%, limited by RMS actuator force. Also, the measurement is influence by the vibrations that travel through the test setup

Alleyne, and Hedrick, (1995) develop a nonlinear adaptive control of active suspensions by applying nonlinear “sliding” control law to an electro-hydraulic suspension system. results from the Simulation and experimental show that the active system is better than a passive system in terms of improving the ride quality of the vehicle. Furthermore, both of the adaptive schemes improve performance, with the modified scheme giving the greater improvement in performance.

Sam et al (2004) develop a robust strategy in designing a controller for an active suspension system which is based on variable structure control theory, which is capable of satisfying all the pre-assigned design requirements within the actuators limitation. The simulation proves the effectiveness and robustness of the control approach.

Fukuda and Shimojima(1999) present a complete comparison of capabilities of different adaptive methodologies (Table 1) together with those of control theory and artificial intelligence

Table1: Comparison Of Capabilities Of Different Adaptive Methodologies

	Mathematical Model	Learning Data	Operator Knowledge	Real Time	Knowledge Representation	Non-linearity	Optimisation
Control Theory	Good or Suitable	Unsuitable	Needs other methods	Good or Suitable	Unsuitable	Unsuitable	Unsuitable
Neural Network	Unsuitable	Good or Suitable	Unsuitable	Good or Suitable	Unsuitable	Good or Suitable	Fair
Fuzzy Logic	Fair	Unsuitable	Good or Suitable	Good or Suitable	Needs other methods	Good or Suitable	Unsuitable
ther Arti cial Intelligence	Needs other methods	Unsuitable	Good or Suitable	Unsuitable	Good or Suitable	Needs other methods	Unsuitable
Genetic Algorithms	Unsuitable	Good or Suitable	Unsuitable	Needs other methods	Unsuitable	Good or Suitable	Good or Suitable

Cao et al (2008) review the state of the art in vehicle active suspension adaptive control systems based on intelligent methodologies which revealed The International Organization for Standardization (ISO) has proposed a series of standards of road roughness classification using PSD values (ISO 1982), as shown in Table II. Due to the ISO, the road displacement PSD can be described as

$$G(n) = G(n_o)\left(\frac{n}{n_o}\right)^{-w}$$

Here, n is the space frequency (m−1), and time frequency f is f = nv (v is the vehicle speed), n0 is the reference space frequency, G(n) is the road displacement PSD, G(n0) is the road roughness coefficient shown in Table II, and w is the linear fitting coefficient, which is always w = 2. Then, based on the standard road surface description, Yu, et al. (2000) presented the road surface input model built through an inform filter by Gaussian white noise.

Table II: Road Roughness Values Classified By Iso(Degree Of Roughness S(n) × 10−6)

Road Class	Range	Geometric mean
A(very good)	< 8	4
B(good)	8-32	16
C(Average)	32-128	64
D(Poor)	128-512	256
E(very poor)	512-2048	1024

Yoshihiro Suda et al(1998) propose Hybrid Suspension System with Skyhook Control and Energy Regeneration (Development of Self-Powered Active Suspension) which reveal that the hybrid control system inflicted with random input, energy flow between high frequency vibration and low frequency vibration takes places. The energy flow improves the isolation performance at low frequency.

Tseng, and Hrovat (2015) provide some insight into the design of suspension control system within the context of existing literature and share observations on current hardware implementation of active and semi-active suspension systems which describe analytical insights and related hardware implementations as valuable and can be applied towards future active or semi-active suspension design.

2.1.1General non-linear active suspension model

Chen et al. (2017) describe an active suspension system by a quarter vehicle model with non-linear stiffness force $F_k(.)$ and damping force $F_c(.)$, as shown in Fig. 3. The model includes the following parameters: m_u and m_s denote the unsprung and sprung masses, respectively; k_t is the tire stiffness; F_a is the actual control force; $F_k(.)$ and $F_c(.)$, indicate the forces produced by the spring and the damper in general, respectively; x_u and x_s are the vertical displacements of the unsprung and sprung masses, respectively; and q is the displacement input of the suspension system from the road irregularity.

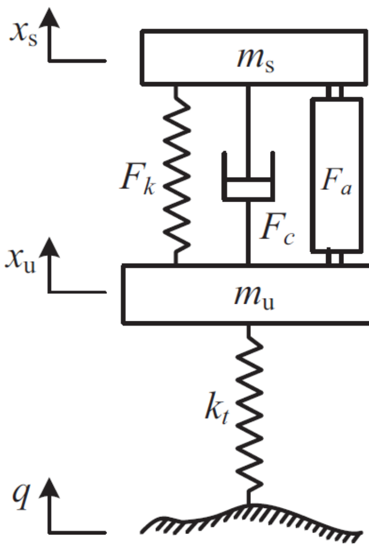

Fig3: Quarter vehicle model with non-linear characteristics.

2.1.2 Control system

The control system is design to provide a desired dynamic behavior of vehicle subject to road disturbances. The design of a position controller is for tracking purpose. The output of the position controller will be a desired force which should be produced by the hydraulic actuator. The force generated by the hydraulic actuator is then controlled to track the desired force. The control system includes two interior loops. The inner loop performs the force control by feedback linearization and the outer loop is a position control loop. The architecture of control system is shown in Fig. 4. The hydraulic actuators are one of the most viable choices due to their high power-to-weight ratio, low cost and robustness.

Fateh and Alavi, (2009) concluded that the method requires a precise model of the system which may not be available and errors are then produced using approximate model. Any error produced by the inner loop will be compensated by the outer loop through a negative feedback.

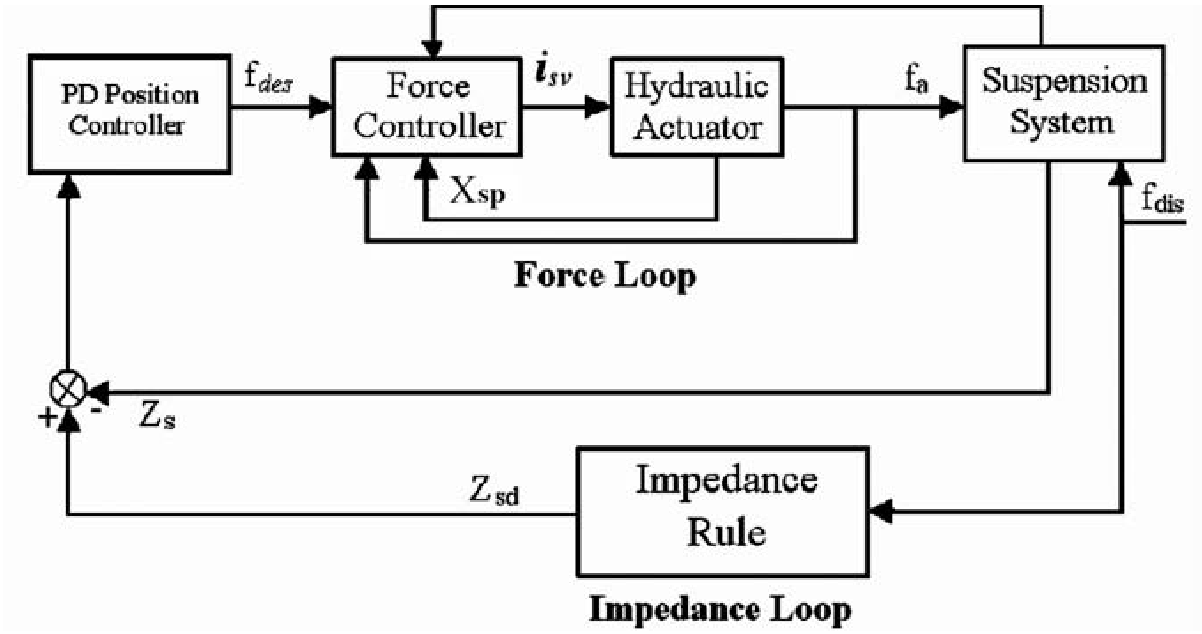

Fig4: The control system

Fateh and Alavi, (2009) developed a novel control system to control dynamic behavior of a vehicle which is subject to road disturbances. They apply the impedance control on an active vehicle suspension system operated by a hydraulic actuator. The simulation results show the performance of control system by comparing the ASS and the PSS. Based on the simulation, it can be concluded that the impedance control of ASS was performed well as it was preferred to PSS. In comparison with model based control laws such as optimal control law, the IR shows important advantages. It is simple, free of model and can be applied for a broad range of road conditions including a flat road.

2.2 Mathematical model of full-car active suspension system

Youness and Lobusov (2019) presented the adopted simulated model of full-car active suspension system (Fig. 5), it consists of a linearized seven degree-of-freedom (DOF) system. In this model, the car body, or sprung mass, is free to heave (Z), roll (φ), and pitch(θ). In the vehicle, heave is vertical motion while pitch and roll are angular motion. Suspension elements between the car body and wheels generate forces that excite heave, pitch and roll motions.

To achieve a linear model, roll and pitch angles are assumed small. The suspension system connects the sprung mass to the four unsprung masses (front-left, front-right, rear-left and rear-right wheels), which are free to bounce vertically with respect to the sprung mass. The suspension system consists of a spring, a shock absorber and a hydraulic actuator at each corner. The shock absorbers are modeled as linear viscous dampers, and the tires are modeled as linear spring (Gaid, 2004).

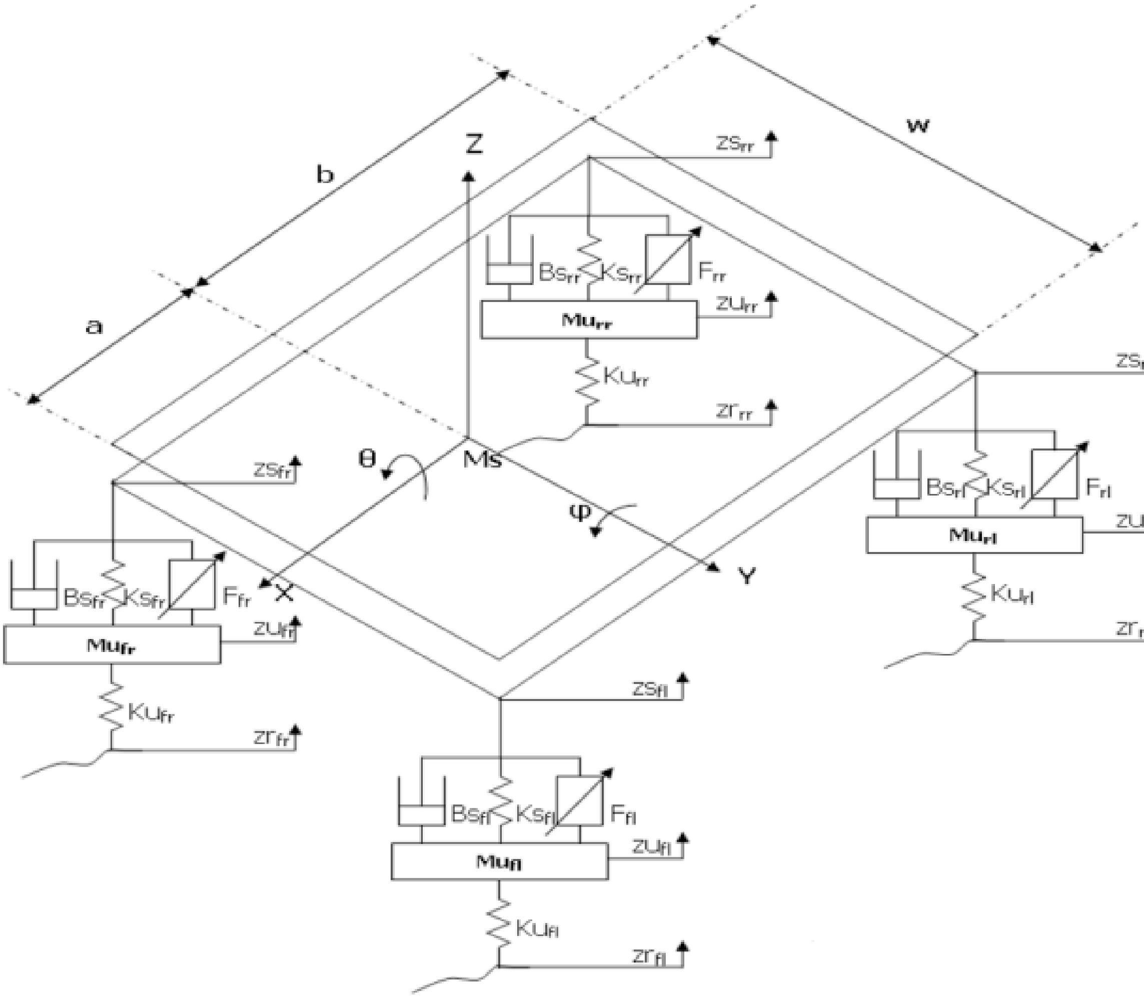

Fig. 5. Active suspension system – full car model.

2.3ACTIVE CONTROL SYSTEM DESIGN

Ikenaga (2000), proposed a closed-loop system (Fig. 6). It consist of inner loops to reject terrain disturbances, outer loops to stabilize heave, pitch and roll responses and an input decoupling transformation that blends the inner and outer control loops. The outer control loops give the attitude control that maintains load-leveling and load distribution during vehicle movements, while the inner control loops provide the ride control that isolates the car body from tire vibrations caused by uneven terrain. The correct blending of the controls generated by the inner and outer loops is a good design of a control system. It was shown that motions of the sprung mass above and below the wheel frequency could be mitigated by using active filtering of spring and damping coefficients through inner control loops (ride controller) plus skyhook damping of heave, pitch and roll velocities through outer control loops (attitude controller).

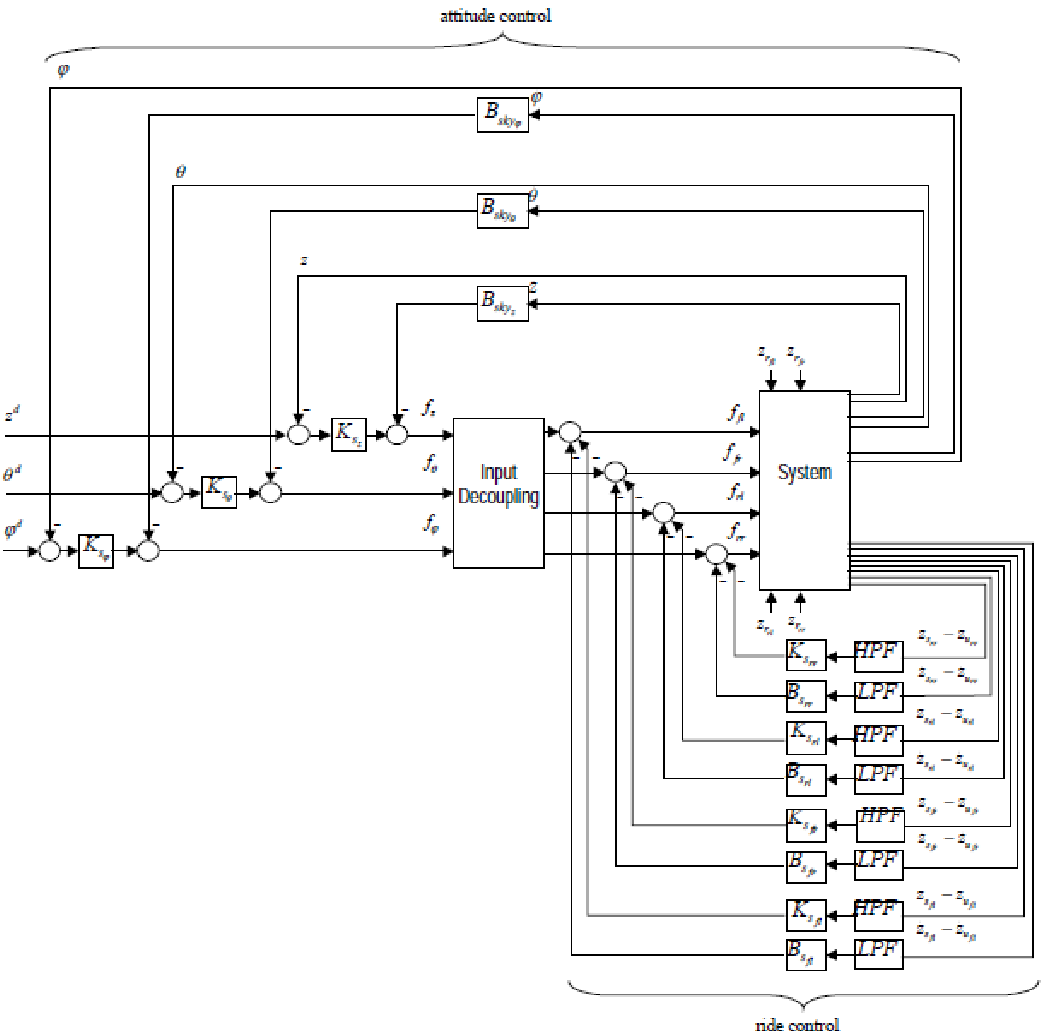

Figure 6. Active filtered feedback control system

CHAPTER THREE

3.0 Materials and Methods

3.1 Materials

3.2

3.3 Characterization

CHAPTER FOUR

4.0 Results and Discussion

4.1 Structure

4.2 Tensile mechanical properties

4.3 Discussion

CHAPTER FIVE

5.0 CONCLUSION

5.1 Limitations and future research

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