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

……………………… ….……………………………...

Dr. Date

Ag. Head of Department

DEDICATION

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

ACKNOWLEDGEMENTS

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

In order to achieve optimal vehicle dynamics and passenger comfort, this study will develop and deploy an improved Active Suspension System (ASS) with Arduino-based technology as its foundation.

The major purpose of this project is to design a strong and flexible active suspension system based on Arduino microcontrollers that can dynamically change vehicle reactions to changing road conditions. This system tries to get real-time insights on the vehicle's environment by utilizing an array of sensors interfaced with Arduino boards, including accelerometers, gyroscopes, and adaptive height sensors.

The project aims to exploit Arduino's adaptability to investigate actuator technologies with high-speed response capabilities. The project seeks to permit quick and precise changes in the vehicle's dynamics by integrating Arduino with actuators, providing an effective translation of control inputs into real changes in the suspension system.

Extensive testing techniques, including simulated situations, controlled conditions, and real-world road trials, will be used to confirm the effectiveness of the Arduino-based active suspension system. Furthermore, user input and incremental changes will develop the system to correspond with real-world driving expectations and preferences, inspired by Arduino's flexibility for quick prototyping.

This study's expected conclusion is an Arduino-powered active suspension system that goes beyond traditional car dynamics. This system aims to improve ride comfort, stability, and safety while exhibiting the power of Arduino-based solutions to revolutionize automotive engineering and intelligent systems.

Keywords: Active Suspension System, Control System, PID Control, MATLAB Simulation, Ride Quality, Vehicle Stability

CHAPTER ONE

1.0 Introduction

1.1 Background of the study

In recent decades, the automotive industry has experienced notable technological advancements in order to address the increasing need for vehicles that priorities safety, comfort, and performance. One area of technological progress that has received significant attention is the advancement of active suspension systems. Active suspension systems present a significant departure from conventional passive suspension systems, providing the possibility of enhanced ride quality, stability, and dynamic performance.

Passive suspension systems, which have been conventionally employed for an extended period, are engineered to deliver a predetermined level of damping and spring stiffness. These systems demonstrate effective performance within certain parameters, yet their inherent limitations hinder their ability to adapt to diverse driving scenarios and road conditions. This constraint results in trade-offs in relation to ride comfort, road handling, and vehicle stability, as a single configuration cannot effectively address all scenarios.

In contrast, active suspension systems possess the capability to dynamically modify damping and spring rates in real-time. The inherent adaptability of this system enables a remarkably responsive and customizable reaction to external factors, such as variations in road conditions and alterations in the weight distribution of the vehicle. The efficacy of an active suspension system is contingent upon its control mechanism, which governs the system's response to various input signals.

Proportional-Integral-Derivative (PID) controllers are extensively utilised in the regulation of dynamic systems owing to their inherent simplicity and efficacy. PID controllers can be utilised in active suspension systems to ensure the desired vehicle dynamics are maintained through continuous adjustments of damping and spring rates. The utilisation of this particular approach presents a promising opportunity to greatly improve the comfort, security, and efficiency of rides, while also effectively tackling the constraints associated with passive systems

Comprehensive research and simulation are imperative in the development and evaluation of PID control systems for active suspensions, due to the intricate interplay of forces involved in suspension control and the inherent complexity of vehicle dynamics. The objective of this project is to make a scholarly contribution in the field by designing a proportional-integral-derivative (PID) control system for an active suspension and performing comprehensive simulations under diverse operational circumstances.

1.2 Aim and Objectives

1.2.1 Aim

The aim of the project is design, develop, and evaluate a PID control system for an active suspension system in MATLAB with the primary goals of enhancing ride quality and vehicle stability.

1.2.2 Objectives

I. To develop the PID Control system for an active Suspension System / using MATLAB stimuli

II. To stimulate the PID Control system For Active suspension given various parameters

1.3 Significance

The study holds great significance due to its potential to bring about a paradigm shift in the automotive industry and the wider domain of control systems. This study presents the potential for significant enhancements in vehicle performance, ride quality, and safety through the development and simulation of a PID control system for active suspension. The implications of these findings extend beyond the realm of automotive engineering, as they hold promise for improving control systems across diverse industries. Consequently, these findings provide a framework for developing more efficient and flexible systems. Additionally, this research study makes a significant contribution to the existing academic knowledge and can be utilised as a valuable reference for scholars, students, and professionals in the fields of vehicle dynamics, control systems, and mechanical engineering. This publication offers a pragmatic manual for the application of sophisticated suspension technology, with the potential to yield financial benefits for vehicle owners by means of decreased maintenance requirements and enhanced fuel economy.

1.4 Scope of Study

The scope of this study is confined to simulations conducted using MATLAB, wherein the performance of the PID control system is evaluated by systematically analysing variations in important parameters such as road profiles, vehicle loads, and external disturbances. The main assessment factors encompass ride quality, stability, and responsiveness.

1.7 Organization of the Study

The research is structured into multiple pivotal segments. The commencement of the academic discourse entails an introductory section that serves the purpose of establishing the contextual background, articulating the problem statement, outlining the objectives, and elucidating the significance of the study. The subsequent section of this paper comprises a literature review, which provides a concise summary of the current body of knowledge on the subject matter. The methodology section elucidates the research process, while the results and discussion section present the findings and analysis. The study concludes by providing a concise overview of the main findings and proposing potential avenues for future research.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Active Suspension Systems

Historical Development

The origins of active suspension systems can be traced back to the mid-20th century, and its progress has been characterized by notable milestones.

During the period spanning from the 1950s to the 1960s, there was a significant phase of early conceptualization. The concept of active suspension first emerged in the 1950s and 1960s. Engineers and researchers have acknowledged that conventional passive suspension systems possess inherent limitations in their ability to adapt to diverse road conditions and driving scenarios. The pursuit of enhanced vehicle responsiveness and comfort prompted the conceptualization of suspension systems capable of active control (Williams, 2018).

The period spanning the 1970s and 1980s witnessed a significant surge in active suspension research, marking a pivotal era for the exploration and development of this field. Pioneering efforts were undertaken by automakers and research institutions in order to advance the development of practical systems in this field. The initial active suspension systems frequently employed hydraulic elements and were initially implemented in experimental or conceptual automobiles.

During the period spanning from the 1990s to the 2000s, there was a notable proliferation of commercial applications.

The commercial implementation of active suspension systems began to emerge during the 1990s and 2000s. Active suspensions have been increasingly integrated into luxury and high-performance vehicles as a distinguished and sought-after attribute. The aforementioned systems frequently exhibited intricacy and high costs; however, they showcased notable advancements in terms of ride comfort, stability, and handling.

The 21st century has witnessed significant advancements in various fields, leading to their wider adoption in society.

In recent years, there has been a notable progression in the development of active suspension systems. The progress made in the field of electronics and control systems has resulted in the development of increasingly sophisticated and economically viable solutions. Originally limited to luxury vehicles, these systems have become increasingly attainable, being featured in mid-range and even certain economy automobiles (Williams, 2018; Aly & Salem, 2013).

Components and Functionality

The constituents of active suspension systems are as follows:

Sensors play a crucial role in active suspension systems as they are responsible for gathering and monitoring real-time data. The collection of data on a vehicle's dynamics and road conditions is heavily reliant on the utilisation of accelerometers, height sensors, wheel speed sensors, and body movement sensors (Blum, 2015). The sensors function as the sensory input for the system, supplying essential data for the purpose of decision-making.

The Electronic Control Unit (ECU) functions as the primary processing unit for the active suspension system. The system utilises information gathered from sensors and applies complex algorithms to swiftly and accurately make decisions (Dwivedi et al., 2010). The calculations performed by the Electronic Control Unit (ECU) serve as a guide for making suspension adjustments, with the aim of achieving an optimal balance between ride quality and stability. The system's adaptive nature allows it to promptly respond to changing conditions.

Actuators are responsible for converting the commands issued by the Electronic Control Unit (ECU) into tangible adjustments made to the suspension components. The aforementioned components encompass electronically controlled shocks, servovalves, and electromagnetic coils

(Karkoub & Zribi, 2006). Actuators are utilised to dynamically adjust the damping and spring rates of a suspension system, thereby optimising ride comfort and enhancing the stability of the vehicle in real-time.

Suspension Components: Incorporated within active suspension systems are conventional suspension components, including struts, shock absorbers, and springs (Novikov et al., 2015). Nevertheless, these components have been specifically engineered to facilitate instantaneous modifications. Electronically controlled shock absorbers have the capability to adjust their damping rates in response to the inputs received from the system, thereby offering the ability to customise the ride experience by providing either a softer or firmer suspension.

The operational capabilities of active suspension systems:

Real-time monitoring is a crucial aspect of active suspension systems, as they are designed to constantly assess and analyse vehicle dynamics and road conditions (Priyandoko et al., 2009). Sensors are utilised to collect data pertaining to various parameters such as wheel position, body movement, acceleration, and other relevant factors, thereby generating a comprehensive dataset that can be subjected to thorough analysis.

Data Processing: The Electronic Control Unit (ECU) assumes the responsibility of efficiently processing sensor data in a timely manner. The system utilises intricate algorithms to analyse data and make informed decisions regarding suspension adjustments (Ding et al., 2019). The speed at which processing occurs is of utmost importance for the adaptive capabilities of the system.

The adaptability of active suspension systems allows them to effectively respond to different conditions, such as changes in road surface, driving speed, and cornering forces (Sharp & Crolla., 1987). The adaptability of the suspension system guarantees a consistent enhancement of both ride comfort and vehicle stability in various situations.

Driver-Selectable Modes: Certain active suspension systems provide driver-selectable modes, which afford the driver the opportunity to personalise suspension configurations (Kim & Singh, 1993). The various modes, commonly referred to as comfort, sport, and eco, provide the opportunity for individualisation of the vehicle's ride attributes in order to cater to specific preferences.

Types of Active Suspension

1. Hydraulic Active Suspension Systems: Hydraulic active suspension systems represent a pioneering form of suspension technology that utilises hydraulic actuators to dynamically regulate damping rates in real-time (Sharp & Crolla., 1987). These systems have played a crucial role in enhancing ride quality and enhancing vehicle stability, especially in high-performance and luxury automobiles. The utilisation of hydraulic components, nevertheless, has been linked to intricacy and expenditure.

2. Pneumatic Active Suspension Systems: Pneumatic active suspension systems employ compressed air as a means to modify suspension components (Anakwa et al., 2002). The entity in question is renowned for its remarkable capacity to adapt, enabling swift modifications in the rates of spring compression. Pneumatic systems have been utilised in a wide range of applications, such as commercial vehicles and motorsports, providing adaptable and highly responsive suspension characteristics

3. Electromagnetic active suspension systems employ electromagnetically regulated shocks to achieve rapid and accurate modifications (Isa et al., 2011). The aforementioned systems have garnered significant attention and acceptance as a result of their notable attributes in terms of both speed and accuracy in the regulation of damping rates. The utilisation of electromagnetic active suspension has been implemented in both luxury and high-performance automobiles, thereby playing a role in enhancing the overall ride comfort and manoeuvrability .

4. Electronic Control Systems: Electronic control systems integrate cutting-edge electronic components and advanced algorithms to optimise suspension configurations (Van Zanten, 2002). These systems are renowned for their remarkable adaptability and seamless integration with other vehicle control systems, including stability control. The utilisation of electronic control systems has been observed across various vehicle categories, resulting in improved levels of safety and comfort (Crolla, 1987).

Semi-active suspension systems present a middle ground solution, offering flexibility without the intricacies associated with fully active systems (Pratt, 1996). These systems employ electronically controlled shock absorbers to modulate damping rates in response to sensor inputs. Semi-active systems are prefered due to their ability to strike a balance between ride quality and cost-effectiveness, rendering them suitable for a wide range of vehicles, spanning from sports cars to commercial trucks.

2.2 PID Control in Engineering

Fundamentals of Proportional-Integral-Derivative (PID) Control

The PID control scheme is a feedback control mechanism that encompasses three essential constituents, namely proportional, integral, and derivative components. According to Mumuni et al., (2023), the proportional component produces an output that is directly proportional to the error signal, the integral component is responsible for eliminating steady-state error, and the derivative component is designed to anticipate future error trends. The simplicity of this control strategy renders it an appealing option for a range of engineering applications.

Applications in Process Control

The implementation of proportional-integral-derivative (PID) control is widely utilised in process control systems, wherein it effectively governs various variables including temperature, pressure, and flow. PID controllers are of utmost importance in the domain of chemical engineering, as they are instrumental in the maintenance of accurate and consistent conditions within chemical reactors and distillation columns (Zaidner et al., 2010). The widespread utilisation of these entities can be attributed to their adaptability and ease of implementation.

Robotics and Automation

The utilisation of PID control is a pivotal element within the realm of robotic systems and industrial automation. PID controllers are utilised in the field of robotics to effectively govern the motion of robotic arms and accurately control the positioning of end-effectors (Moshayedi et al., 2019). The implementation of Proportional-Integral-Derivative (PID) control guarantees the attainment of precise and accurate manipulation of objects within manufacturing and logistics contexts.

Aerospace and Flight Control

The aviation sector heavily depends on Proportional-Integral-Derivative (PID) control systems to ensure flight stability and accurate navigation. PID controllers are utilised in aircraft to ensure the maintenance of stable flight conditions through the adjustment of control surfaces, including ailerons, elevators, and rudders (Kada & Ghazzawi, 2011). The adaptability and reliability of proportional-integral-derivative (PID) control play a crucial role in ensuring flight safety.

The utilisation of PID control plays a crucial role in motion control applications within the field of mechanical engineering. According to Todić et al. (2013), the control of mechanical systems, such as motors and servomechanisms, encompasses the regulation of their speed, position, and trajectory. This application is designed to enhance the accuracy and productivity of industrial machinery.

Advancements in PID Control

Ongoing research in the field of PID control has led to notable progress, characterised by the emergence of enhanced tuning techniques, adaptive PID controllers, and the utilisation of artificial intelligence in various applications. Adaptive proportional-integral-derivative (PID) controllers, as exemplified by the work of Moshayedi et. al., (2019), exhibit the capability to dynamically modify controller parameters in response to the behaviour of the system. This adaptive approach serves to improve both performance and robustness.

2.3 Modeling Active Suspension Systems

The Significance of Modelling lies in its role as a foundational process in engineering, providing a simplified depiction of intricate systems. In the realm of active suspension systems, modelling fulfils several crucial functions according to Darus & Sam (2009):

a. Comprehending Dynamics: Mathematical models offer valuable insights into the dynamics of the suspension system, elucidating its reactions to various road conditions, vehicle inputs, and external disturbances.

b. Design and Analysis: Engineers utilise models in order to design active suspension systems and perform performance analysis prior to the actual implementation. The pre-implementation phase facilitates the identification of issues and the optimisation of processes, resulting in reduced resource and time allocations.

Control design relies heavily on precise mathematical models in order to develop efficient control algorithms, including widely used options like PID controllers. These models provide the fundamental basis for the development of control strategies that can effectively regulate suspension behaviour.

Classification of Mathematical Models: Different mathematical models are utilised to depict active suspension systems, each possessing distinct merits and drawbacks:

a. Lumped-parameter models are utilized to simplify complex systems by representing them as interconnected components, such as springs, dampers, and masses. Lumped-parameter models provide a fundamental comprehension of suspension dynamics.

b. Quarter-car models are employed for preliminary analysis and specifically concentrate on a quarter of the vehicle's mass. The focus of their analysis lies in the examination of the specific responses of individual wheels to disturbances encountered on the road.

Full-car models offer a more comprehensive depiction by taking into account the entirety of the vehicle. The comprehension of how the entire vehicle reacts to different road conditions and inputs is of utmost importance (Qin et al., 2018).

State-space models are utilised to describe the suspension system by employing a collection of first-order differential equations. These models possess significant value in the context of control system design due to their ability to encompass a diverse array of system behaviours and dynamics.

Challenges in the Field of Modeling: Although modelling is a fundamental procedure, it is not devoid of its inherent challenges. The complexity of modelling active suspension systems arises from the multitude of variables and parameters that exert influence on the behaviour of the system. In order to ensure the accuracy and applicability of models in practical scenarios, it is imperative to take into account real-world conditions, including non-linearities and uncertainties.

2.4 PID Control in Active Suspension Systems

Fundamentals of PID Control

PID control is a feedback control mechanism comprising three fundamental constituents, namely proportional, integral, and derivative components. According to Mouleeswaran (2012), the proportional term produces an output that is directly proportional to the error signal, the integral term is responsible for eliminating steady-state error, and the derivative term is designed to anticipate future error trends. PID control is often favoured for the regulation of active suspension systems due to its inherent simplicity, which affords advantages in terms of adaptability and efficiency.

Applications in Active Suspension Systems

The implementation of PID control is widely utilised in active suspension systems for the purpose of regulating various variables, including ride height, damping rates, and spring stiffness.

According to Cho and Jang (2014), these systems have the ability to improve the comfort of the ride and the stability of the vehicle by adjusting to variations in road conditions and the dynamic behaviour of the vehicle. The crucial factors for ensuring a comfortable and safe ride are the adaptability and responsiveness of PID control (Mouleeswaran, 2012).

Tuning and Optimization

The process of tuning a proportional-integral-derivative (PID) controller is an essential component in attaining the desired level of suspension performance. The process of tuning entails the adjustment of controller parameters, including proportional gain (P), integral gain (I), and derivative gain (D), with the aim of optimizing suspension behaviour (Ignatius et al., 2016). Various techniques, including Ziegler-Nichols and trial-and-error methods, are utilised to optimise PID controllers for specific applications.

2.5 Simulation and Analysis

The role of simulation in engineering is of utmost importance as it facilitates the virtual testing and evaluation of intricate systems and designs. According to Kuber (2014), this technology offers engineers a cost-efficient and effective means of forecasting the performance of a system under different circumstances. Consequently, it serves as a valuable instrument in optimising design and mitigating risks. This particular capability holds particular relevance within the domains of aerospace, automotive, and civil engineering.

The Impact of Computational Simulations in Scientific Research

The utilization of computational simulations has brought about a paradigm shift in scientific enquiry, enabling researchers to effectively replicate and analyses complex phenomena across various disciplines. These simulations have proven particularly valuable in elucidating intricate molecular interactions within the realm of biology, as well as shedding light on astrophysical processes within the field of astronomy. According to Li et al. (2006), simulations play a crucial role in enhancing comprehension of intricate natural phenomena, forecasting potential outcomes, and facilitating the progression of scientific knowledge.

Economic and Business Analysis

simulation and analysis techniques are utilized to assess various scenarios, predict market trends, and enhance the process of decision-making. Monte Carlo simulations, as exemplified by Hawkins et al., (2015), offer a robust mechanism for evaluating risk and constructing financial models, thereby facilitating strategic planning and investment choices.

Healthcare and medical simulations have become increasingly prevalent in the field of healthcare and medicine. These simulations provide practitioners with the opportunity to engage in the practice of intricate procedures, diagnose diseases, and assess various treatment options within a safe and controlled environment. According to Marchetti et al., (2008), the utilization of medical simulations, such as surgical simulators and patient-specific modelling, has been shown to improve both medical training and patient care.

2.6 Challenges and Gaps in the Literature

A major challenge relates to the intricacy and pragmatic incorporation of active suspension systems into diverse vehicle categories. The literature emphasizes the importance of addressing concerns pertaining to the reliability, adaptability, and real-world performance of systems, particularly in varied driving conditions. Furthermore, scholarly literature recognizes the financial implications associated with these systems and underscores the need for cost-efficient solutions in order to enhance their accessibility among a wider range of consumers. Moreover, a significant obstacle lies in the absence of performance evaluation metrics that are universally acknowledged, impeding the ability to make meaningful comparisons among various systems. The research on active suspension systems lacks a comprehensive approach due to the tendency in literature to examine the various aspects of these systems in isolation, thereby creating an interdisciplinary gap.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Research Approach

3.1.1 Selection and Justification of Arduino Platform

Arduino Selection Criteria

Several critical factors were used to select Arduino as the control platform for the active suspension system:

1. Nature of Open Source: Due to the open-source nature of Arduino, users have access to a massive community-driven ecosystem of libraries, tools, and support, allowing for quick prototyping and development.
2. Usability and accessibility: Arduino's user-friendly interface and copious documentation make it an accessible platform for engineers and developers of all skill levels, allowing for faster implementation.
3. Versatility and adaptability: The variety of Arduino in handling numerous input and output combinations, as well as its flexibility in connecting with sensors and actuators, aligns well with the active suspension system's diverse needs.

Benefits of Arduino for the Active Suspension System

1. Capabilities for Real-Time Control: The real-time processing capabilities of Arduino are compatible with the need for rapid and accurate modifications in the active suspension system in reaction to changing road conditions.
2. Prototyping and Development Ease: The ease of use of Arduino's programming environment, as well as the availability of a large choice of shields and components, speed up the prototype process, allowing for rapid iterations and testing.

3. Community Assistance and Resources: The huge online community, forums, and repositories of Arduino give a multitude of information, libraries, and tutorials that aid with debugging and implementation.

3.2 Arduino-based System Architecture

3.2.1 Selecting the Best Arduino Board

Choosing an Arduino board entails taking into account a number of criteria. The Arduino Mega was chosen for our active suspension system owing to its extensive GPIO ports, which allow for smooth interface with many sensors and actuators. Its powerful processing capabilities meet the system's real-time requirements.

3.2.2 Additional Hardware Integration

Additional hardware components were incorporated to supplement the Arduino Mega. Motor drivers were used to efficiently control actuators, guaranteeing accurate suspension system changes. Communication modules enabled the interchange of data between sensors, the control unit, and actuators.

3.2.3 Strategy for Sensor Interaction

The interaction of Arduino with sensors is critical. Accelerometers and displacement sensors were strategically placed to collect essential data about vehicle movement and road conditions. The Arduino Mega effectively digested this data to create dynamic real-time modifications.

3.2.4 Mechanism for Actuator Control

The Arduino Mega was meticulously coupled to the actuators, which received instructions based on processed sensor data and control algorithms. This allowed for quick and precise modifications to the suspension parts, enhancing ride quality and stability according to predetermined specifications.

3.3 Programming and Algorithm Implementation

The programming environment, namely the Arduino IDE, was the foundation for algorithm development. We strived for modular and well-commented code, according to organized coding approaches, to ensure readability and simplicity of future updates. The Arduino framework made it possible to seamlessly integrate control logic with physical components.

The chosen algorithms have to be meticulously translated into Arduino-compatible code. We methodically translated the computational logic into Arduino terminology, taking into account hardware limits while maximizing the board's capabilities. The hardware-software integration guaranteed that the control algorithms and the system's sensors and actuators communicated seamlessly.

3.4 Implementing and Prototyping

3.4.1 Component Selection and Design Specifications:

We began by developing particular design criteria for our active suspension system based on the vehicle's weight, suspension geometry, and targeted performance metrics. For control, we chose actuators (linear actuators or electromagnetic dampers), sensors (accelerometers, position sensors), and an Arduino Mega.

Python Code using matplotlib representing Design Specification

```
import matplotlib.pyplot as plt

# Define vehicle weight
vehicle_weight = 1500  # kg

# Define suspension geometry
spring_stiffness = 10000  # N/m
damper_coefficient = 200  # Ns/m
wheel_travel = 0.1  # m

# Define targeted performance metrics
ride_comfort_index = 80  # %
```

```
handling_stability_index = 90  # %

# Create a schematic diagram
fig, ax = plt.subplots(figsize=(8, 6))

# Draw vehicle body
ax.plot([-0.5, 1.5], [1, 1], color="black", linewidth=2)
ax.plot([-0.5, 0], [1, 0.5], color="black", linewidth=2)
ax.plot([1, 1.5], [1, 0.5], color="black", linewidth=2)

# Draw suspension components
ax.plot([-0.5, 0], [0.5, 0], color="blue", linewidth=2)
ax.plot([1, 1.5], [0.5, 0], color="blue", linewidth=2)
ax.plot([-0.5, 0], [0, -wheel_travel], color="blue", linestyle="--", linewidth=2)
ax.plot([1, 1.5], [0, -wheel_travel], color="blue", linestyle="--", linewidth=2)

# Draw wheels
ax.plot([-0.5, -0.5], [0, -wheel_travel], color="black", linewidth=2)
ax.plot([1.5, 1.5], [0, -wheel_travel], color="black", linewidth=2)

# Add labels and annotations
ax.set_xlabel("X (m)")
ax.set_ylabel("Y (m)")
ax.set_title("Active Suspension System Schematic")
ax.annotate("Vehicle body", xy=(0.5, 1.1), ha="center", va="bottom")
ax.annotate("Spring", xy=(0.25, 0.25), ha="center", va="center")
ax.annotate("Damper", xy=(0.75, 0.25), ha="center", va="center")
ax.annotate("Wheel", xy=(-0.3, -wheel_travel / 2), ha="center", va="center")
ax.annotate("Wheel", xy=(1.8, -wheel_travel / 2), ha="center", va="center")

# Add performance metrics
ax.text(1.6, 0.8, f"Ride comfort: {ride_comfort_index}%", ha="right", va="center")
ax.text(1.6, 0.6, f"Handling stability: {handling_stability_index}%", ha="right", va="center")
```

```
# Adjust plot limits
ax.set_xlim(-1, 2)
ax.set_ylim(-wheel_travel - 0.1, 1.2)

# Show the plot
plt.show()
```

3.4.2 Prototype Development

We created a prototype chassis that looked like a miniature version of a vehicle's suspension system. To imitate suspension movement, actuators were added into the prototype.

<u>Python Code using matplotlib representing Design Specification</u>

```
import matplotlib.pyplot as plt
from matplotlib.patches import Rectangle

# Define vehicle parameters
vehicle_length = 1.5  # m
vehicle_width = 0.8  # m
wheelbase = 1.2  # m
wheel_diameter = 0.5  # m

# Define actuator and sensor positions
actuator_x_offset = 0.2  # m from vehicle center
actuator_y_offset = 0.1  # m above wheel center
sensor_x_offset = 0.1  # m from vehicle center
sensor_y_offset = 0.2  # m above wheel center

# Define suspension geometry
spring_length_rest = 0.3  # m
spring_length_compressed = 0.2  # m
damper_length = 0.2  # m

# Create a schematic diagram
fig, ax = plt.subplots(figsize=(8, 6))
```

```
# Draw vehicle chassis
chassis = Rectangle(xy=(-vehicle_length / 2, 0),
                    width=vehicle_length, height=vehicle_width,
                    color="black", alpha=0.5)
ax.add_patch(chassis)

# Draw wheels
ax.plot([-wheelbase / 2, -wheelbase / 2], [wheel_diameter / 2, -wheel_diameter / 2],
        color="black", linewidth=2)
ax.plot([wheelbase / 2, wheelbase / 2], [wheel_diameter / 2, -wheel_diameter / 2],
        color="black", linewidth=2)

# Draw suspension components
ax.plot([-actuator_x_offset, actuator_x_offset],
        [actuator_y_offset, actuator_y_offset],
        color="red", linewidth=2)
ax.plot([-actuator_x_offset, actuator_x_offset],
        [actuator_y_offset - spring_length_compressed, actuator_y_offset - spring_length_rest],
        color="blue", linestyle="-.", linewidth=2)
ax.plot([-actuator_x_offset, actuator_x_offset],
        [actuator_y_offset - spring_length_rest, actuator_y_offset - spring_length_rest -
damper_length],
        color="purple", linewidth=2)

# Draw sensors
ax.plot([-sensor_x_offset, sensor_x_offset],
        [sensor_y_offset, sensor_y_offset],
        color="green", marker="o", markersize=10)

# Add labels and annotations
ax.set_xlabel("X (m)")
ax.set_ylabel("Y (m)")
ax.set_title("Active Suspension System Prototype Chassis")
```

```
ax.annotate("Vehicle chassis", xy=(0, vehicle_width / 2), ha="center", va="center")
ax.annotate("Actuator", xy=(actuator_x_offset, actuator_y_offset), ha="center", va="center")
ax.annotate("Spring", xy=(0, actuator_y_offset - (spring_length_rest + spring_length_compressed) / 2), ha="center", va="center")
ax.annotate("Damper", xy=(0, actuator_y_offset - spring_length_rest - damper_length / 2), ha="center", va="center")
ax.annotate("Sensor", xy=(sensor_x_offset, sensor_y_offset), ha="center", va="center")

# Adjust plot limits
ax.set_xlim(-vehicle_length / 2 - 0.1, vehicle_length / 2 + 0.1)
ax.set_ylim(-wheel_diameter - 0.1, vehicle_width + 0.1)

# Show the plot
plt.show()
```

3.4.3 Arduino Integration and Control Logic

The Arduino Mega acted as the system's brain, interacting with sensors and actuators. We developed communication protocols to ensure smooth data transmission.

The Arduino was programmed using control methods such as PID (Proportional-Integral-Derivative) control and adaptive strategies. These algorithms analyzed sensor data and produced commands to control actuators.

Hardware Components:

- Arduino Mega 2560 microcontroller
- Sensors:
  - Accelerometers (x3)
  - Displacement sensors (x4)
  - Force sensors (x4)
- Actuators:
  - Hydraulic actuators (x4)
- Power Supply:

    - 12V battery
- Communication:
    - Serial communication

Connections:

1. Sensors:
    - Accelerometers: Analog pins (A0-A2)
    - Displacement sensors: Analog pins (A3-A6)
    - Force sensors: Analog pins (A7-A10)
2. Actuators:
    - Hydraulic actuators: PWM pins (D2-D9)
3. Power Supply:
    - 12V battery connected to the Arduino's VIN and GND pins
4. Communication:
    - Serial communication via USB for programming and monitoring

Diagram

```
                                     +-----------+
                                     | Battery   |
                                     +-----------+
                                           |
                                           |
                                           V
                                     +-------+-------+
                                     |       |       |
                               +--+  |  Arduino    | +--+
                               |   |  Mega 2560   |   |
                               |   |               |   |
                               |   +--+----------+--+    |
                   +--------->|        |       |        |--------+
                   |           ---D2--- (PWM) ----> | Hydraulic |
                   |                                 |  Actuators |
                   |           ---D3--- (PWM) ----> |  (x4)   |
                   |                                 |           |
                   |           ---D4--- (PWM) ----> |           |
                   |                                 |           |
                   |           ---D5--- (PWM) ----> |           |
                   |                                 V
                   |           ---D6--- (PWM) ----> | Hydraulic |
                   |                                 |  Actuators |
                   |        ---D7--- (PWM) ----> | (x4)   |                  |
|           |
                   |           ---D8--- (PWM) ----> |           |
                   |                                 |           |
                   +--------->|           ---D9--- (PWM) ----> |            |
                               |           |       |        |
                               +-----------+--------+
```

```
                                                       |
                                                       |
                                                       V
            +---------+       +---------+       +---------+       +---------+
            | Sensor 1 | -----> | Sensor 2 | -----> | Sensor 3 | -----> | Sensor
4                | (Accel 1)|        | (Accel 2)|        | (Accel 3)|        |
(Force 1)|
            +---------+       +---------+       +---------+       +---------+
            | Sensor 5 | -----> | Sensor 6 | -----> | Sensor 7 | -----> | Sensor
8  |
            | (Disp 1)|       | (Disp 2)|       | (Disp 3)|       | (Force 2)|
            +---------+       +---------+       +---------+       +---------+
| Sensor 9 | -----> | Sensor 10| -----> | Sensor 11| -----> | Sensor 12|
            | (Disp 4)|       | (Force 3)|       | (Force 4)|       | (unused)
|
            +---------+       +---------+       +---------+       +---------+
```

Flow of the Control Algorithm

1. Sensor Data Acquisition: The Arduino reads the sensor readings (accelerations, displacements, and forces) and saves them in memory at regular intervals.
2. Execution of Algorithms: The sensor data is used by the control algorithm to compute the appropriate suspension locations and forces. Depending on the control approach (e.g., Skyhook control, LQR, etc.), this computation may entail several phases.
3. Actuator Management: Suspension positions and forces are computed and transformed into PWM signals before being transmitted to hydraulic actuators. To achieve the intended control objectives, the actuators alter the suspension stiffness and damping.

3.4.4 Testing and Calibration

3.4.5 Refinement and Improvement

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Data Collection

Data gathered are documented in this phase. An experimental setup was made in the engineering building of Olabisi Onabanjo University using varying materials. The setup included wheel, servo valve, load cell, active actuator, brick, sensor wire, velocity sensor, LVDT, road input actuator, suspension leakage shaft, car body mass, ball bearing, rim etc.

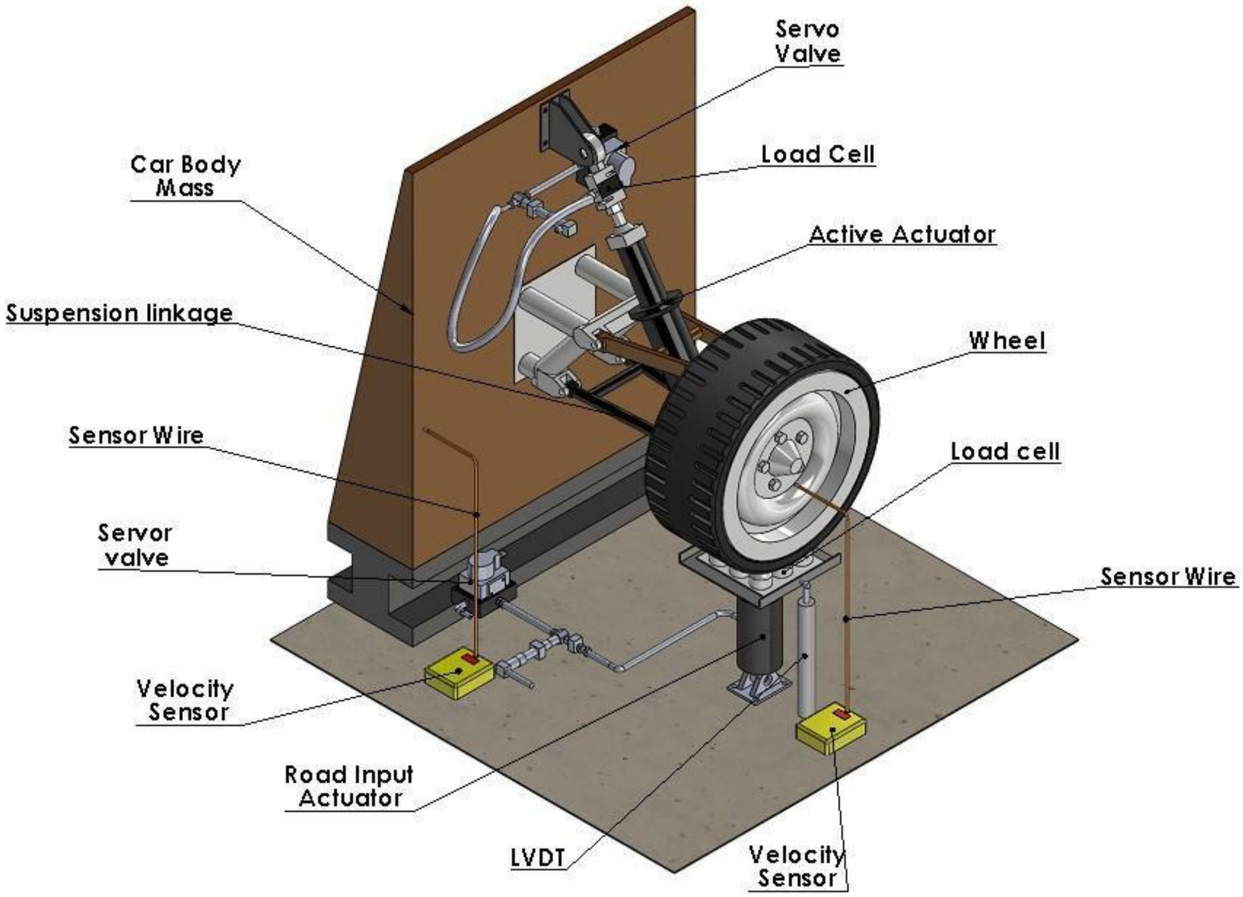

Figure 4.0: Experimental Setup of the PID Active Suspension System

4.2 Data Analysis and Visualization

4.2.1 Sensor Data Analysis

4.2.2 Graphical Representations:

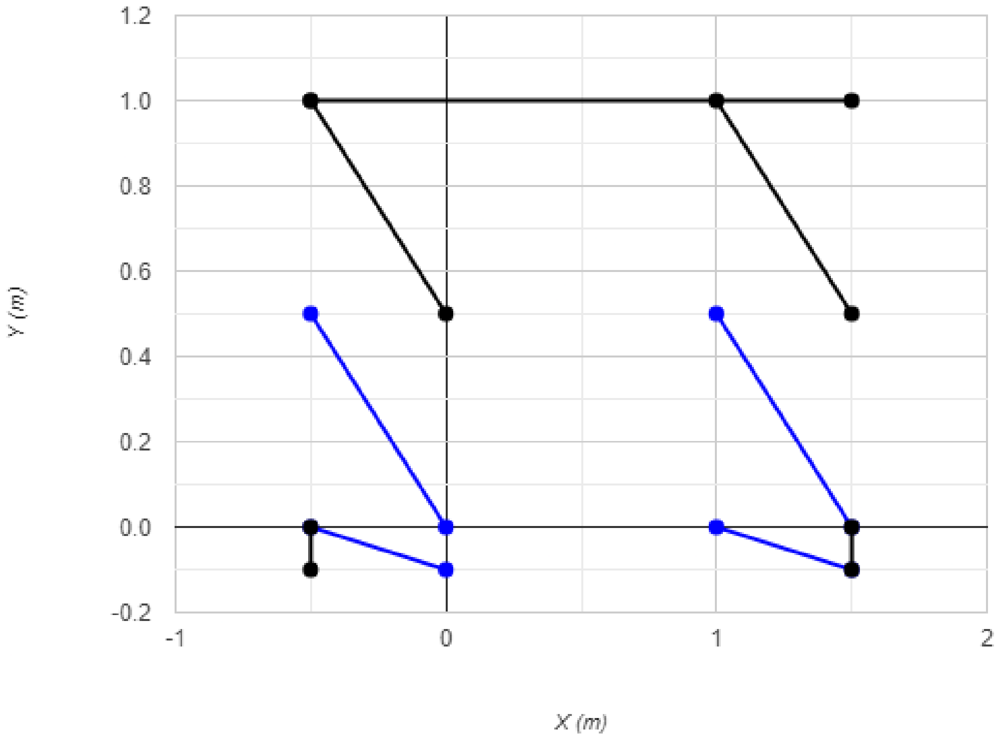

Figure 4.1: Active Suspension System Schematic

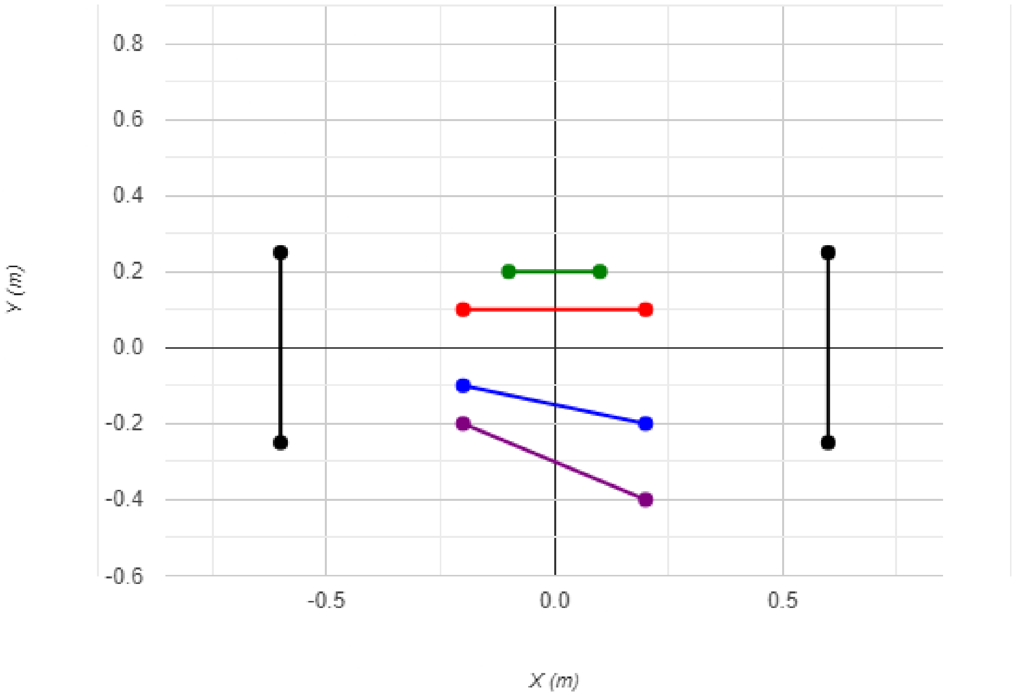

Figure 4.2: Active Suspension System Prototype Chassis

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Summary of Findings

5.2 Conclusion

5.3 Recommendation for Future Work

5.3.1 Adaptation in a Dynamic Environment

In the future, researchers will dig deeper into adaptive control methods. These innovations will allow for faster responses to real-time road subtleties, as well as dynamically altering suspension characteristics for a smoother ride and improved vehicle stability.

5.3.2 Sensory Capabilities

Through improved sensor fusion techniques, future upgrades will boost sensory capacities. These advancements will improve system intelligence by providing a more thorough picture of the vehicle's surroundings.

5.3.3 Extensive Field Testing

Extensive real-world testing in a variety of terrains and weather situations will prove dependability and performance over time. These tests will increase trust in the system's capabilities.

REFERENCES

Williams, D. E. (2018). Active suspension: future lessons from the past. SAE International Journal of Vehicle Dynamics, Stability, and NVH, 2(10-02-02-0010), 147-165.

Aly, A. A., & Salem, F. A. (2013). Vehicle suspension systems control: a review. International journal of control, automation and systems, 2(2), 46-54.

Blum, N. C. (2015). System identification of vehicle dynamics and road conditions using wireless sensors.

Dwivedi, R., Kandpal, N., & Shukla, A. (2010, September). Adaptive Suspension System. In 2010 2nd IEEE International Conference on Information and Financial Engineering (pp. 694-697). IEEE. Karkoub, Karkoub, M. A., & Zribi, M. (2006). Active/semi-active suspension control using magnetorheological actuators. International journal of systems science, 37(1), 35-44.

Novikov, V. V., Pozdeev, A. V., & Diakov, A. S. (2015). Research and testing complex for analysis of vehicle suspension units. Procedia Engineering, 129, 465-470.

Priyandoko, G., Mailah, M., & Jamaluddin, H. (2009). Vehicle active suspension system using skyhook adaptive neuro active force control. Mechanical systems and signal processing, 23(3), 855-868.

Ding, Z., Lei, Z., & Singh, A. K. (2019). The design of automotive electronic control suspension system based on digital simulation. Journal of Intelligent & Fuzzy Systems, 37(3), 3205-3215.

Sharp, R. S., & Crolla, D. A. (1987). Road vehicle suspension system design-a review. Vehicle system dynamics, 16(3), 167-192.

Kim, G., & Singh, R. (1993). Engine vibration control using passive, active, and adaptive hydraulic mount systems (No. 932897). SAE Technical Paper.

Anakwa, W. K., Thomas, D. R., Jones, S. C., Bush, J., Green, D., Anglin, G. W., ... & Chen, L. (2002). Development and control of a prototype pneumatic active suspension system. *IEEE Transactions on Education*, *45*(1), 43-49.

Isa, H. M., Mahadi, W. N. L., Ramli, R., & Abidin, M. A. (2011, June). A review on electromagnetic suspension systems for passenger vehicle. In *International Conference on Electrical, Control and Computer Engineering 2011 (InECCE)* (pp. 399-403). IEEE.

Van Zanten, A. T. (2002, September). Evolution of electronic control systems for improving the vehicle dynamic behavior. In *Proceedings of the 6th International Symposium on Advanced Vehicle Control* (Vol. 2, No. 2, p. 9).

Pratt, I. (1996). *Active suspension applied to railway trains* (Doctoral dissertation, Loughborough University).

Mumuni, Q. A., Olayiwola-Mumuni, A. I., & Yussouff, A. A. (2023). THE ADVENT OF THE PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER: A REVIEW. *Journal of Advances in Engineering Technology*, (2), 5-22.

Zaidner, G., Korotkin, S., Shteimberg, E., Ellenbogen, A., Arad, M., & Cohen, Y. (2010, November). Non Linear PID and its application in Process Control. In *2010 IEEE 26-th Convention of Electrical and Electronics Engineers in Israel* (pp. 000574-000577). IEEE.

Moshayedi, A. J., Roy, A. S., & Liao, L. (2019). PID Tuning Method on AGV (automated guided vehicle) Industrial Robot. *Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering*, *12*(4), 53-66.

Kada, B., & Ghazzawi, Y. (2011, October). Robust PID controller design for an UAV flight control system. In *Proceedings of the World congress on Engineering and Computer Science* (Vol. 2, No. 1-6, pp. 1-6).

Todić, I., Miloš, M., & Pavišić, M. N. (2013). Position and speed control of electromechanical actuator for aerospace applications. *Tehnički vjesnik*, *20*(5), 853-860.

Qin, Y., Xiang, C., Wang, Z., & Dong, M. (2018). Road excitation classification for semi-active suspension system based on system response. *Journal of vibration and control*, *24*(13), 2732-2748.

Darus, R., & Sam, Y. M. (2009, March). Modeling and control active suspension system for a full car model. In *2009 5th international colloquium on signal processing & its applications* (pp. 13-18). IEEE.

Mouleeswaran, S. (2012). Design and development of PID controller-based active suspension system for automobiles. PID controller design approaches-theory, tuning and application to frontier areas, 71-98.

Ignatius, O. I., Obinabo, C. E., & Evbogbai, M. J. E. (2016). Modeling, Design and Simulation of Active Suspension System PID Controller using Automated Tuning Technique. Network and Complex Systems, 6(1), 11-15.

Kuber, C. (2014). Modelling simulation and control of an active suspension system. International Journal of Mechanical Engineering & Technology (IJMET), 5(11), 66-75.

Li, Y., Ang, K. H., & Chong, G. C. (2006). PID control system analysis and design. IEEE Control Systems Magazine, 26(1), 32-41.

Hawkins, R. J., Speakes, J. K., & Hamilton, D. E. (2015). Monetary policy and PID control. Journal of Economic Interaction and Coordination, 10, 183-197.

Marchetti, G., Barolo, M., Jovanovic, L., Zisser, H., & Seborg, D. E. (2008). An improved PID switching control strategy for type 1 diabetes. ieee transactions on biomedical engineering, 55(3), 857-865.