# PRINCIPLES OF AUTOMATION AND CONTROL: THEORY AND PRACTICE

PART 1

Editor:

**Ilesanmi Afolabi Daniyan**

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# Principles of Automation and Control: Theory and Practice

## *(Part 1)*

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**Principles of Automation and Control: Theory and Practice *(Part 1)***

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# CONTENTS

# FOREWORD

With the rapid emergence of technological innovations, the industrial and manufacturing landscapes are becoming increasingly complex and dynamic, creating a growing need for automation and control. Automation ensures that processes and systems are regulated automatically, enhancing operational efficiency and enabling independent functioning. By maintaining consistent quality and optimizing production volume in a time- and cost-effective manner, automation helps manufacturing industries achieve their key goals of productivity and profitability. Consequently, the degree of automation and control within an industrial setting largely determines the efficiency, consistency, safety, and overall progress of industrial processes, including their measurement, regulation, manipulation, and visualization. This edited volume brings together a diverse collection of studies and research in the field of automation and control, covering topics ranging from enabling technologies to hardware and software requirements. It provides valuable insights from experts and scholars, presenting the principles of automation and control from multidisciplinary perspectives to promote shared knowledge and expertise. The book encompasses conceptual, theoretical, and empirical studies, effectively bridging the gap between theory and practical application. Moreover, it highlights the transformative impact of automated systems across multiple sectors, including manufacturing, healthcare, energy, and agriculture.

The book explores both foundational principles and emerging trends in automation and control, offering a practical, guided approach to the development and implementation of robust control algorithms and systems. It demonstrates the integration of advanced sensors for data acquisition, which forms the basis of effective control and automation. Additionally, it examines the application of machine learning techniques and real-time data analytics for improved decision-making. The contributions presented are novel, expanding the understanding of automation and control while offering practical solutions to real-world industrial challenges.

This book is an invaluable resource for students, researchers, engineers, professionals, and practitioners at all levels. The examples, innovations, and experiences it presents have the potential to deepen knowledge and keep readers abreast of the latest developments in the field. With great pleasure, I commend the authors, editors, and reviewers for their astuteness and depth of understanding demonstrated in this book. As a book with significant contributions to the field of automation and control, I strongly recommend it to readers with the assurance that it will foster new ideas and innovation.

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# PREFACE

The quest for increased productivity, effective control, high product quality, reduced manufacturing cycle time, and cost efficiency has driven significant research interest in the field of automation and control. Automation lies at the heart of modern industrial society and is pervasive across engineering sectors, including manufacturing and process industries. It forms the foundation of contemporary manufacturing systems, which are characterized by speed, precision, high-volume productivity, and operational independence. With the continuously evolving industrial and manufacturing landscape, the need for robust automation and control systems has become imperative to address the demands and challenges of modern manufacturing. The development of automated and control systems, propelled by digital transformation and technological advancement, promotes efficiency, innovation, and sustainability across diverse fields such as healthcare, energy, manufacturing, robotics, and process industries.

This book is particularly timely as it explores current trends in the digital transformation of industrial and manufacturing processes and the enabling technologies that support them. The first volume, Principles of Automation and Control I, laid the groundwork by covering essential topics such as the principles and classes of automation, control theories, instrumentation, and robotics, thereby introducing the fundamental concepts of control system design.

This second volume, Principles of Automation and Control II, is divided into two parts consisting of twenty-five comprehensive chapters that cover conceptual, theoretical, empirical, and practical examples of automation and control systems. The book is divided into two parts. This Part 1 comprises of thirteen chapters (Chapters 1-13) covering fundamentals of digital systems for automation, automation, additive manufacturing, control system and its practical applications, optimization strategies, artificial intelligence application and Internet of Things (IoT) applications.

It serves as both instructional and reference material, providing a foundational text for students, researchers, and professionals seeking to deepen their understanding of automation and control theory and its applications.

The book begins with the concepts and theories of digital automation and industrial control, including system modeling and control system design. It then progresses to advanced digital control systems for industrial automation, highlighting modern control and automation devices such as Programmable Logic Controllers (PLCs), sensors, and actuators. Additionally, it explores practical applications of emerging technologies such as the IoT and AI as enablers of automation and control. What sets this book apart is its emphasis on both theoretical and practical aspects, with numerous examples, case studies across various fields, and practical exercises designed to bridge the gap between theory and implementation.

This book aims to equip readers with the theoretical and practical knowledge necessary to design, implement, monitor, and analyze automation and control systems in real-world settings. When carefully studied, it provides insights into innovations that are poised to shape the future of industrial control systems and automation.

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# CHAPTER 1

# Fundamentals of Digital Systems for Automation: Programmable Logic Devices (PLDs) and Programmable Logic Controllers (PLCs)

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**Abstract:** Advancements in digital automation have revolutionised industrial control systems, fostering the transition from traditional relay-based mechanisms to more intelligent and adaptable solutions. This chapter goes deeper into how Programmable Logic Devices (PLDs) and Programmable Logic Controllers (PLCs) are being used in modern automation today, distinguishing each in terms of how and why they are used, and then brings readers through the vast number of applications that this technology is being used for. The use of a digital control system leads to better operational efficiency with reduced downtime and system reliability. Hardware implementations in PLDs provide solutions for custom logic implementation, and in PLCs for the necessary real-time functions that are required for industrial automation tasks. These technologies were implemented in manufacturing operations and smart infrastructures to optimise process and energy management systems as well as robot processes. In the future, the popular trends, including Artificial Intelligence (AI) automation, edge technology, and Industrial Internet of Things (IIoT), will continue to impact the evolution of the digital system. Also, these technological advancements allow us to do better predictive analytics and make faster, decentralised decisions coupled with adaptive automation. This chapter shows how digital control technology makes intelligent automation systems intelligent and is key to future development.

**Keywords:** AI, Automation system, Control technology, PLC, PLD, IIoT.

## INTRODUCTION

Digital systems have already made a change in the automation landscape a decade or more ago. Today, industries that rely on mechanical and analogue technologies have transitioned to the digital form; these technologies have become highly

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efficient, precise, and adaptable. The evolution of the control system is driven by the increasing demand for intelligent, automated solutions that have impacted sectors of manufacturing, healthcare, energy, and transportation.

Modern automation is founded on digital systems, which provide very sophisticated hardware and software to drive greater operational capabilities. Important components that have emerged are technologies such as Programmable Logic Devices (PLDs) and Programmable Logic Controllers (PLCs), which enable precise control and real-time decision-making. They represent an alternative to traditional relay-based technology that offers flexibility, scalability, and high reliability.

Going ahead, as multiple industries embrace digital automation, interconnected systems, data analytics, and artificial intelligence will continue to play an important role in the development. By being able to process such large amounts of information in real-time, predictability of maintenance, self-optimising workflow, and more sustainable processes are possible. Adding the digital piece to automation is not merely about bettering efficiency, but also about facilitating a smarter, safer, more dynamic industrial environment.

## INTRODUCTION TO DIGITAL AUTOMATION

Digital technology has been advancing at a rapid pace and has been influencing the process of how industries are controlled, monitored, and executed [1, 2]. First, the systems of automation initially relied on mechanical and analogue systems, but they changed to digital systems providing more efficiency, accuracy, and flexibility [3, 4]. Digital automation has brought rise to industrial productivity by seamlessly integrating intelligent systems in multiple sectors such as manufacturing, healthcare, transportation, infrastructure development, *etc* [5 - 8].

The idea of automation is not new; basic mechanical systems were created to achieve repetitive work with little human intervention [6]. As time went by, technological developments brought in the electrical and electronic slave control mechanisms and incorporated Programmable Logic Controllers (PLC), microprocessors, and embedded systems. Behind this lie these innovations which have allowed these highly sophisticated automated systems to respond dynamically to actual-time data [1, 2, 5].

It is the modern digital automation in which various parts such as actuators, sensors, controllers, and communication networks are integrated to enable real-time decision-making and process optimisation [7 - 9]. Systems can adapt to changing conditions; therefore, collecting and analysing large volumes of data improve operational efficiency and reduce costs [7, 9]. The advancement in

Artificial Intelligence (AI) and machine learning further enhances automation with predictive maintenance, fault detection, and adaptive control mechanisms [5, 6].

## Evolution of Digital Automation

Driven by the demand for increased productivity, safety, and precision [4, 10, 11], the journey toward full digital automation has begun from manual control. Mechanical linkages require that there be significant human intervention to adjust and maintain the operations in early automation systems [12, 13]. Electrical relays, which introduced a huge step forward in the techniques by which processes can now be controlled with electrical rather than mechanical components, were introduced [14]. Relay-based systems, however, had issues, such as frequent wear out, slow response, complex wiring, and so on.

During the late 1960s, the PLCs came into being and thus changed industrial automation. Compared with a relay control system, which used cumbersome devices that altered circuitry to carry out functions, these digital controller systems offered flexible and reconfigurable control processes that were programmed. PLCs enabled engineers to create sophisticated control sequences without the need for extensive rewiring, increase the reliability of the system, and decrease downtime. With increased power technology in microprocessors, PLCs have gained more power such as real-time monitoring, internet connectivity and integration with assisted supervisory systems [15, 16].

This was further accelerated by the proliferation of microcomputers and embedded systems [7, 15]. These compact computing devices increased processing power, allowing fine control of industrial processes [17]. This enabled the integration of sensors, communication modules, and control algorithms into a single embedded system that opens up new avenues of automated fields such as robotics and medical devices [9, 14].

Fig. (**1**) shows the progression of the digital automation system from basic mechanical control to advanced AI-powered automation.

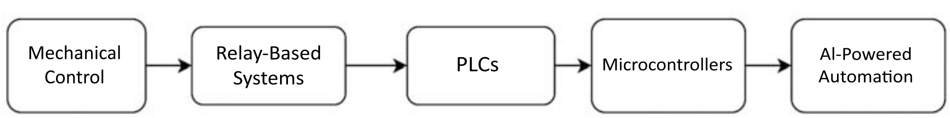


**Fig. (1).** Evolution of industrial digital automation.

# CHAPTER 2

# Industrial Control and Automation: PLCs, PID Controllers, Microcontrollers, and Microprocessors

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**Abstract:** Automation has revolutionised industrial processes through the integration of sophisticated control systems, enhancing efficiency, accuracy, and adaptability. This chapter examines the fundamental components of industrial automation, focusing on the role of Programmable Logic Controllers (PLCs), Proportional-Integral-Derivative (PID) controllers, microprocessors, and microcontrollers. These technologies facilitate intelligent process control, enabling industries to optimise performance and reduce reliance on manual interventions. The discussion highlights how PLCs provide flexible and programmable solutions for automation, while PID controllers enhance system stability and precision. Microprocessors and microcontrollers contribute computational power and embedded intelligence, allowing for real-time data processing and adaptive control. The transition from traditional hardwired systems to software-driven automation has streamlined industrial operations, reducing costs and improving scalability. Emerging trends, including artificial intelligence, Internet of Things (IoT) integration, and predictive analytics, are shaping the next generation of industrial automation. These advancements are fostering the development of smart factories and interconnected systems that operate with greater autonomy and efficiency. Embracing these technologies can enable industries to achieve significant improvements in productivity, sustainability, and competitiveness, ensuring long-term growth in an increasingly automated world.

**Keywords:** Automation, IoT, Microcontrollers, Microprocessors, PID, PLC.

## INTRODUCTION

Automation has emerged as a transformative force in modern industry, enabling enhanced productivity, precision, and operational efficiency across various

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sectors. The integration of advanced control systems, including Programmable Logic Controllers (PLCs), Proportional-Integral-Derivative (PID) controllers, microprocessors, and microcontrollers, has revolutionised how industries manage complex processes. These technological advancements have streamlined industrial operations, reduced human intervention, and improved system reliability, making automation indispensable in sectors such as manufacturing, energy, transportation, and healthcare.

The shift from manual and mechanical systems to intelligent digital control solutions has been driven by the need for greater efficiency, accuracy, and adaptability. Traditional hardwired control systems were labour-intensive and inflexible, requiring extensive rewiring for modifications. The introduction of microprocessor-integrated control systems, such as PLCs and microcontrollers, provided a more scalable and adaptable alternative, allowing engineers to implement changes through software rather than hardware modifications.

With the increasing complexity of industrial applications, automation technologies have evolved to incorporate real-time processing, predictive analytics, and machine learning. These innovations have paved the way for smart factories, interconnected systems, and autonomous decision-making, creating an ecosystem where machines and control systems work collaboratively to optimise performance. This chapter explores the fundamental components of industrial automation, focusing on the roles of PLCs, PID controllers, microprocessors, and microcontrollers in achieving seamless, intelligent automation, as well as on software: MATLAB/Simulink, FX Trainer, and GX Developer.

The practical illustration on how to set up the GX developer and program a PLC is presented in the appendix.

## PROGRAMMABLE LOGIC CONTROLLERS (PLCS): FROM STRUCTURE AND FUNCTION TO PROGRAMMING

In industrial applications, the PLC is a common type of microprocessor-integrated control system. It emerged as an alternative to traditional, hardwired control systems. Think of the microprocessor as the brain of the operation. A program provides the intelligence, guiding the microprocessor's actions. It dictates how to interpret signals from switches and other devices, and how to create the output signals that drive motors, valves, and other equipment [1, 2].

In contrast, traditional control systems rely on fixed wiring to define the control logic and trigger actions. Updating the control logic in a traditional system requires rewiring, which can be time-consuming and complex [3, 4].

The key advantage of microprocessor-integrated systems like PLCs is their adaptability. With just a few tweaks to the program, the same microprocessor system can adapt to a wide variety of tasks and applications [5, 6].

## Working Principle of PLCs

PLCs are microprocessor-integrated controllers. They use programmable memory to store instructions that control machines and processes. These instructions handle logic, sequencing, timing, counting, and arithmetic. Engineers with basic computer and programming knowledge can easily operate PLCs. Instead of requiring complex programming skills, PLCs are pre-programmed to allow users to input control programs using a simple, user-friendly language [2, 3, 7].

PLC operation involves:

i. Input Acquisition: PLCs receive input signals from various devices such as switches and sensors.
ii. Program Execution: The PLC's processor executes the stored program, interpreting the instructions and making decisions based on the input signals.
iii. Output Generation: The PLC generates output signals to control devices such as motors, valves, and actuators based on the program logic.

Unlike traditional hardwired control systems, PLCs do not have a direct physical connection between input and output devices. This flexibility allows for easy modifications and adaptations to changing control requirements by simply updating the program [8]. The control of an input device (switch) and an output device (bulb) using a PLC is shown in Fig. (**1**).

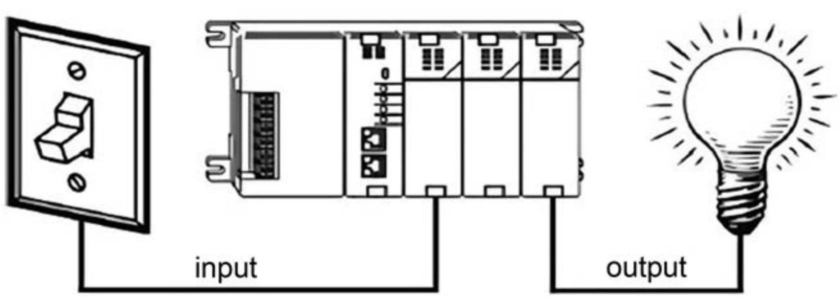


**Fig. (1).** PLC connection [9].

One of the key advantages of PLCs is their versatility. Using the same fundamental controller, a PLC can be adapted to control a wide range of systems. Modifying the control system simply requires updating the program with a new

# CHAPTER 3

# Advanced Digital Systems for Automation: CNC and CAD/CAM

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**Abstract:** Industrial operations in today's world depend on automation technologies for enhancing digital optimization because they raise business process productivity while protecting procedural accuracy and creating flexible system components. The research on automation development focuses on moving to Computer Numerical Control (CNC) machines supported by Computer Aided Design (CAD)/Computer Aided Manufacturing (CAM) systems and Artificial Intelligence (AI) and Internet of Things (IoT) technology implementation. Industrial institutions obtain two main capabilities through digital automation technologies that support improved procedures and automated resource management for optimization purposes. The CNC machine executes precision manufacturing because it delivers automatic systems that produce exact industrial procedures through repeatable operations. Product development shortens its duration and produces better results through the integration of CAD/CAM software between design work and manufacturing processes. Production based on data insisted manufacturers to use AI and IoT systems as part of automation, which performed predictive maintenance alongside real-time monitoring and smart decision-making. Businesses that integrate smart technology into automated systems must address three main challenges including cybersecurity threats as well as the need to train workers and handle implementation expenses. Although some hurdles persist, the advantages of digital automation produce more benefits that promote productivity, together with sustainability and enhanced competitiveness for industries.

Digital automation progresses through multiple steps that incorporate breakthroughs concerning Artificial Intelligence, as well as quantum computation and advanced system connectivity. The future standard of manufacturing depends on self-operating production lines and smart factories, so industrial operations need to adapt to emerging technologies through rising automation trends.

**Keywords:** Artificial intelligence, Automation, CAD, CAM, IoT.

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## INTRODUCTION

Digital technology used in modern industrial automation processes created manufacturing operational changes that produced improved operating efficiency results. The implementation of digital solutions enabled superior precision in operations, with flexible design properties and transformable functionality that exceed mechanical systems' typical operating limits. Ultra-secure machine-to-machine systems that integrate CNC machinery and CAD/CAM technology help businesses achieve superior efficiency goals while minimising errors and eliminating work delays. Organisations using modern automation developments now exceed basic technological advancement levels for both innovative operations and competitive market performance in fast-evolving business sectors.

Manufacturing receives growing support from AI, the Internet of Things (IoT), and machine learning due to increasingly advanced digital automation. Real-time decision-making, along with the predictive maintenance and self-learning capabilities of these technologies, helps enterprises improve efficiency and productivity. Advanced operations in smart factories are enabled by connecting sensors and platforms to machines *via* cloud-based networks, leading to improved management of operations and resources.

The evolution of CNC technology, starting with numerical control, has shown continuous progress in automation throughout its development. Industrial sectors, including aerospace manufacturing, automotive, and medical device manufacturing, depend on CNC machines for their precise operation, high efficiency, and repeatability. The implementation of CAD/CAM software improves these features by creating a smooth design-to-production workflow that reduces production time and material waste.

The chapter evaluates the growth of digital automation by analysing CNC machine roles and presenting CAD/CAM system applications alongside the extensive industrial automation impact of AI and IoT. These technologies have continued to evolve in the way they influence modern industries and control future automation development.

Software: CNC Simulator Pro

## CNC MACHINES AND AUTOMATED MANUFACTURING

The automation system, known as a CNC machine, performs precise part manufacturing through digital control methods. The different sectors of the automotive industries, alongside aerospace and medical devices, heavily rely on these systems due to their critical need for accuracy, efficiency, and repeatability capabilities.

CNC systems convert computer designs into physical products through the regulation of machine-tool motions, regulation of lathes and milling machines, as well as routers [1, 2].

The machines execute their operations through programs that hold alphanumeric encoded commands. The program guides all machine operations and performs instructions through [1 - 5]:

i. The control of machine cutting operations requires determining both the movement path and operating speed.
ii. Setting parameters: Adjusting factors like feed rate (how fast the tool moves), depth of cut, and spindle speed.
iii. Controlling machine functions: Activating or deactivating the spindle (rotating part) and coolant system.

The CNC follows these coded instructions and produces highly accurate and complex parts with exceptional speed and consistency.

## THE BIRTH OF CNC: FROM ROTOR BLADES TO REVOLUTION

The need to mass-produce helicopter rotor blades spurred the development of NC (Numerical Control) machines. In 1947, John C. Parsons, a manufacturer of rotor blades, faced the challenge of speeding up template production. He devised a system that linked computer equipment to a jig borer, with operation controlled by punched cards. This system, known as Digit Ron, laid the groundwork for modern CNC technology [5].

The US Air Force recognized the growing complexity of aircraft and weapon components, with frequent design revisions. To address this, they commissioned Parsons Corporation, with MIT's servo mechanics laboratory as a subcontractor, to investigate faster production methods. In 1951, MIT took over the project and successfully demonstrated a modified milling machine in 1952, marking the birth of the modern NC machine. The term “numerical control” itself originated at MIT [5].

CNC technology has evolved significantly, encompassing various machine types, including [1 - 6]:

# CHAPTER 4

# Advancements and Applications of Additive Manufacturing in the Automotive Industry

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**Abstract:** Additive Manufacturing (AM), otherwise known as 3D printing, is transforming the automotive sector by increasing design freedom, decreasing manufacturing costs, and improving efficiency. AM enables rapid prototyping, facilitating a fast-track to product development while minimising material waste. AM also enables the production of lightweight, high-strength parts, improving the automobile's fuel efficiency and performance. Furthermore, AM enables mass customisation of parts, enabling auto manufacturers to create components for their vehicles based on customer preferences. This technology optimises supply chain logistics by producing spare parts on demand rather than keeping inventory, resulting in cost savings and sustainability. Various methods for AM, such as Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and Direct Metal Laser Sintering (DMLS), are often used for prototyping, tooling, and end-use parts. A qualitative research design was employed, primarily through a thorough literature review of the applications, advantages, challenges, and future perspectives of AM in automotive enterprises. The necessary data that was collected encompassed findings from academic journals and conference papers, as well as industry reports and case studies on Ford, BMW, and General Motors, as well as other emerging technologies. Overall, the findings suggest that AM can improve vehicle production with rapid prototyping, lighter-weight components, mass customisation, cost-effective production, and design flexibility. Nevertheless, the main unforeseen challenges include AM's high initial production costs, slow production speeds, and the lack of universal, reliable material properties. As AM continues to develop, it will have a major role in streamlining automotive manufacturing, reducing the environmental effects of transportation, innovating automotive design and production, and with the long-term potential to disrupt the automotive sector's production model.

**Keywords:** Additive manufacturing, Automotive industry, Customisation, Lightweight components, Rapid prototyping, Sustainability.

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## INTRODUCTION

AM is impacting the automotive industry by providing lighter-weight designs, faster lead times, reduced costs, and increased customisation [1]. It produces complex geometry parts with improved performance while reducing material use and simplifying production [2]. In addition to improving product development timeframes, AM also allows automotive manufacturers to refine supply chains and improve vehicle efficiency using new designs and materials. Throughout the evolution of AM, applications in the automotive sector are increasing, advancing traditional scale production and custom vehicle manufacturing. AM is transforming the automotive industry by enhancing new design possibilities, quick prototyping, cost savings, and sustainability [2 - 4]. Additive manufacturing builds components layer by layer, enabling the fabrication of complex geometric parts with minimal material waste [5]. Historically, the automotive industry has sought ways to improve efficiency and reduce production costs while maintaining high performance requirements [6 - 8]. AM provides a practical approach to achieving improvements in product development timelines, supply chain optimisation, and mass customisation. Auto manufacturers around the world are using AM in many different ways, such as rapid prototyping, lightweight vehicle components, spare parts production, and tooling [9].

Due to advances in AM technologies, the industry is shifting from prototyping to high-volume production, particularly in Electric Vehicles (EVs) and high-performance vehicles [10]. As producers continue to push the envelope of materials and processes, AM will continue to grow and change the landscape of vehicle design, manufacturing efficiency, and sustainability efforts [11]. Over the past several decades, additive manufacturing’s role within the automotive space has changed considerably [12, 13]. Initially, AM was primarily used for rapid prototyping due to its ability to quickly generate design concepts and functional models [14, 15]. However, as AM technologies evolved, producers began to realise the opportunities in producing end-of-use products, disposable products, and complex geometries that were previously not possible through traditional manufacturing [16]. Notable advancements in the development of additive manufacturing within the automotive industry include some major milestones in AM's evolution in the automotive field, which are as follows:

**1980s** – Emergence of AM: 3D printing technologies for automotive prototyping were being developed, including Stereolithographic (SLA) and Selective Laser Sintering (SLS) methods [17].

**1990s** – Prototyping Adoption: Important automotive organizations began using AM to design concept models and validate designs for various parts [18].
**2000s** – Expansion into Tooling and Jigs: AM became a vital tool for producing custom jigs, fixtures, and molds, further improving manufacturing efficiency [19].
**2010s –** End-Use Part Production: Automakers started integrating AM-produced components in vehicles, particularly in high-performance and luxury models [20].
**2020s and Beyond –** Towards Full-Scale Manufacturing: Advancements in metal 3D printing, hybrid manufacturing, and large-scale AM applications are pushing the industry toward mass adoption of AM for vehicle production [21].

The continued evolution of AM has positioned it as a game-changing technology in the automotive sector, enabling manufacturers to enhance product design, reduce development time, and increase production flexibility [22].

In recent years, studies on the uses of additive manufacturing, shown in Fig. (**1**), illustrate the exponential expansion of the vehicle sector. Awesome accomplishments in the domains of cutting-edge manufacturing technology, distinctive advanced printable materials, and high-performance end-use components for the automotive sector have been achieved.

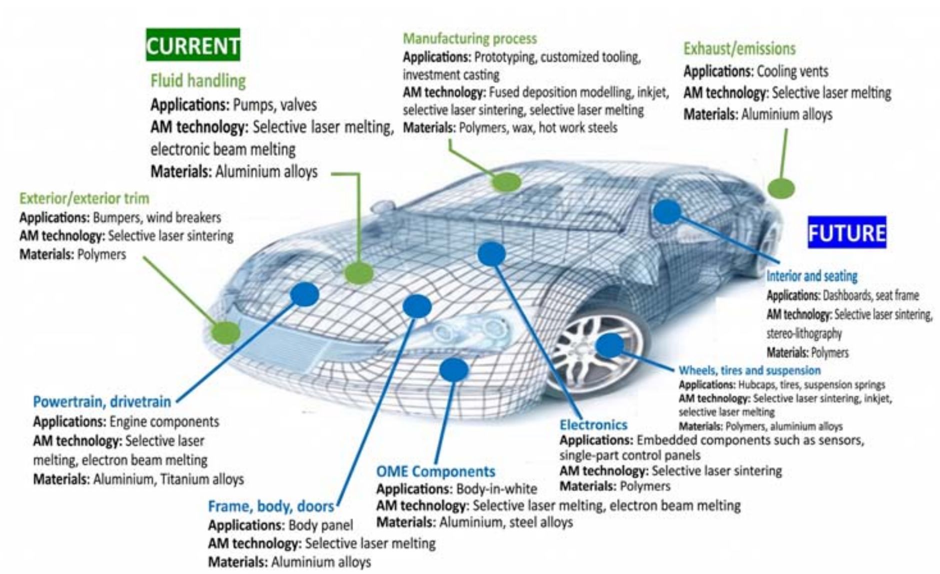


**Fig. (1).** The present utilisation of additive manufacturing within the automotive sector and its future potential [23].

Many studies summarize the current state of research regarding the applications of AM techniques within the automotive sector; these works often fall short of

# CHAPTER 5

# A Review of Control System Techniques for Optimising Efficiency and Design in Mechanical Energy Harvesting within Road Infrastructure

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**Abstract:** This paper presents a systematic review of the literature on control system techniques for enhancing the design and efficiency of Mechanical Energy Harvesting (MEH) systems deployed on road infrastructures, including movable speed humps. The recent advancements in integrating control strategies with MEH systems to maximize vehicular motion energy capture and conversion, particularly through piezoelectric and electromagnetic methods, are investigated in this review. A key focus is placed on the role of control systems in maximizing harvesting performance under various traffic and environmental conditions. This work presents a comprehensive assessment of innovations in MEH modelling, simulation, and integration with urban infrastructure in real-world applications. Studies have shown that optimally controlled MEHs can significantly power roadside equipment, such as traffic lights and streetlights, in off-grid and rural settings. By reducing dependence on traditional fossil fuel-based systems, such technologies allow for cleaner and more sustainable transport networks. The article concludes by highlighting gaps and future opportunities for improved MEH flexibility and long-term efficiency of use.

**Keywords:** Control systems, Energy harvester, Energy conversion, Movable speed humps, Piezoelectric generators, Renewable energy.

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## INTRODUCTION

Advances in the field of a materials revolution have sparked a lot of interest. Speed bumps serve as a frequent tool for regulating vehicle speed and improving safety in high pedestrian traffic areas and residential zones. Regrettably, the energy expended by vehicles when traversing these bumps is typically squandered [1]. Given the growing demand for sustainable energy solutions, it is imperative to explore innovative control system techniques to create an efficient energy system. This review lays the foundation for the utilisation of control system methods to develop a mobile, speed-bump-centred Mechanical Energy Harvesting (MEH) system for roads, optimising energy capture and conversion. The implementation of such technology in nations such as Nigeria effectively addresses pertinent energy deficits, demonstrating that controlled system solutions can transform roadway infrastructure and energy adequacy.

Energy Harvesting (EH) is the concept of an energy harvester, which is a device that captures and converts various forms of energy (vibrations, impacts, or motion, solar, thermal) from the environment into usable electrical energy [2, 3]. The purpose of an energy harvester is to harness and utilize ambient energy sources that would otherwise go to waste [4]. EHs are used widely across the globe in Wireless Sensor Networks, wearable technology, remote monitoring, and self-powered devices [5]. It offers an effective, environmentally friendly approach to powering a wide range of gadgets by tapping available natural resources. MEHs technologies have attracted tremendous interest over the years because of the increasing concern for green energy and energy-autonomous systems. EHs play a role in minimising dependence on conventional energy sources and electricity and are also used in power management across all facets of human life through efficiency gains in various operations.

Furthermore, MEH systems present useful techniques for controlling vibrations since they are present in many realistic scenarios [6]. The mention of vibrations is closely linked to roads, vehicles, machines, constructions, and various natural phenomena. These vibrations provide ample opportunities to harness mechanical energy that can be easily converted into usable power [7]. For instance, in road applications, MEH systems can be installed as speed humps [8] or as a rumble strip, which captures mechanical energy from the vibrations of vehicles and generates electricity [9], in mobile plants like cars, trains, airplanes, bikes, *etc*. The MEH system can be fitted so that, during operation, available vibration energy is utilised to power onboard systems or recharge batteries. Besides, there are many ways to convert mechanical energy from ambient vibrations into electrical energy using diverse types of transducers, each with different advantages depending on the specific application and/or field conditions. Two of the transduction systems that have received considerable research attention are Piezoelectric Generators (PEG) and Electromagnetic Generators (EMG), owing to their relatively simple designs and their capability to produce substantial power levels [6].

PEG normally consists of a cantilever beam of dimensions 6 mm x 3 mm with one or multiple piezoelectric inserts bonded on the surface [10]. EMG, on the other hand, employs macroscopic structures with a coil and a magnet [11], which are mostly built with simple geometries [12]. MEMS-based EMG, comprised of planar coils, planar springs, and permanent magnets, has been reported. These transducer technologies offer viable means to convert ambient vibrations into electrical energy. The choice between piezoelectric and EMG depends on factors such as power requirements, implementation simplicity, and specific application constraints. Researchers have extensively studied and developed macroscopic and MEMS-based structures for both transducer types, paving the way for practical EH solutions [12]. The development of MEH in Nigeria's bump road construction is of utmost importance. Despite the presence of numerous speed bumps on highways and in communities, the utilisation of MEH technology has beenlimited, even though it has been available for over a decade. Nigeria is grappling with the challenge of inadequate electricity generation and supply, leading to limitations in sustaining road traffic signs, street lights, and billboards. These electronic and electrically powered devices are crucial for facilitating vehicle movement during both day and night. Unfortunately, many of these traffic signs heavily rely on power generators fuelled by fossil fuels, contributing to environmental hazards through the emission of harmful gases into the atmosphere [13]. By designing and optimizing an energy harvester that leverages the vibrations generated by cars crossing over road bumps, Nigeria can address the deficiencies in powering traffic signs and ensure a sufficient energy supply to illuminate the roads at night. This technological advancement would greatly enhance road safety by improving visibility for drivers and reducing the incidence of accidents attributed to poor vision at nighttime [14]. Moreover, the utilisation of an EH would have wider implications for sustainability. By reducing dependence on fossil fuel-powered generators, the environmental impact can be significantly mitigated. The harmful emissions associated with traditional power generation methods would be minimized, leading to improved air quality and a healthier environment for both residents and commuters. Implementing Energy Harvesting Technology (EHT) for road bump vibrations presents an opportunity to enhance the reliability and efficiency of electronic devices used in the transportation infrastructure [14]. The self-sufficiency of these devices, powered by renewable and clean energy sources, would reduce operational costs and contribute to the overall sustainability of the transportation system.

# CHAPTER 6

# Application of Control Strategies for Sustainable Microgrids Planning and Operations

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**Abstract:** The energy sector plays a vital role in the economic growth of any nation. The rise in global human population has placed daunting demands on the energy sector and its players, as well as a huge stress on electrical grids, leading to poor electricity supply to consumers. To solve this problem, microgrids (MG) have been designed and deployed as an alternative energy source or to provide ancillary support to the utility grid. However, the sustainable operation of MG depends largely on the control operation, which coordinates the activities within the MG and ensures seamless transitions from one mode to another. Therefore, this study discusses MG and the application of control strategies for the sustainable planning and operation of MG. The various types of MG, their architecture, and the challenges associated with MG planning and operation are discussed. The available control strategies alongside their relevance to the optimal operation of the MG are presented. This study finds that the control aspect of microgrids is pivotal to the successful operation, hence, it must be properly factored at the design stage. This study finds application and provides helpful insights for planners and operators for sustainable MG planning and operation, thereby advancing the realization of Sustainable Development Goals (SDG) 7.

**Keywords:** Control strategies, Energy, MG, SD, Sustainable planning and operation.

## INTRODUCTION

The energy landscape is currently undergoing a significant global transformation that necessitates the need for sustainability, energy resilience, and decarbonization. Microgrids (MG) have emerged as a promising solution, offering

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localized energy systems that integrate renewable energy sources, energy storage, and advanced load management technologies. These systems enable efficient and reliable power supply, even in regions with limited access to centralized grids or during disruptions caused by natural disasters [1]. They offer significant advantages in advancing sustainability, resilience, and energy equity. The concept of MG involves the use and deployment of non-conventional energy sources, such as Photovoltaic (PV), wind, hydro, and biogas, as well as combined heat and power systems, also referred to as distributed generators [2]. The MG is an electrical power system that consists of distributed renewable energy sources, energy storage systems, and loads, which can be operated either in grid-connected or isolated/stand-alone modes [3]. They are solutions for sustainable energy availability in remote communities where renewable energy resources are abundant, making them readily available for power generation. MGs can be operated in two ways: either grid-connected or standalone, otherwise known as island mode. In the grid-connected mode, the MG operates in connection with the grid, while in the island mode, it operates singly without connection with the grid which is self-sufficient.

A MG is viewed as a key component of the future smart grid. It combines dispersed generation and information technologies to build a broadly distributed automated energy delivery network. MGs are capable of delivering electricity to a single building, college, or small town utilizing a combination of decentralized energy resources, such as renewable sources, energy storage, and conventional electricity production [2]. The integration of MGs is transforming global electricity distribution networks. It has the ability to improve power quality, increase energy security for essential loads, and maximize system efficiency. In MGs, the Distributed Energy Resources (DERs) are situated at or near the consumption sites. In contrast to "central generation," DERs or Distributed Generation (DG) can minimise generation, transmission, and distribution costs while enhancing efficiency by removing components complexity and interdependence [1, 3]. A Point of Common Coupling (PCC) connects a macrogrid to a MG's distribution/generation side. They are similar to conventional grid structures in terms of power generation, distribution, and transmission, with control aspects thought to be a minor approximation of actual grid form. However, because a MG is situated near the loads, it differs from a traditional grid in terms of the distance between power generation and consumption cycles. Although the power rate of MGs is limited to a few Mega Volt-Ampere (MVA), it is based on their application region and grid type [3].

Environmental worries regarding centralized electricity generation have been a driving force behind the development of MGs. The MG market is likely to expand further, despite the fact that the most significant quality of MG technology:

resilience, cannot be accurately stated in monetary terms. Various MG deployments or current experiments are being conducted around the world to better understand how MGs work. Many technologies and topologies have been studied for a variety of applications [1].

Unlike traditional centralised power systems, MGs integrate Distributed Energy Resources (DERs) such as solar Photovoltaic (PV) systems, wind turbines, batteries, and combined heat and power systems to serve localized areas. However, their efficient operation depends on sophisticated control strategies that address challenges like variability in renewable energy generation [4]. A number of challenges are associated with optimal performance of MGs. High variability of renewable energy resources is one of the major challenges that confronted optimal performance of MGs. The solution to address this problem are basically by overrating the design of MGs capacity and by hybridising multiple energy sources to ensure that the system perform its expected functions. Effective hybridisation of multiple energy sources requires application of control strategy to operate efficiently. As a result, there are a number of control techniques that have been developed and applied for sustainable operation of MGs. Distributed control strategy is one of the most widely used control of MGs for effective energy transaction management [5, 6]. The capabilities of hierarchical control system for Distributed Generators (DGs) have been exploited for recognising the necessity of maintaining an optimal voltage profile for essential loads within an MG [7]. The use of predictive control techniques based on the application of Model Predictive Control (MPC) and Artificial Neural Networks (ANN) to anticipate the future dynamic behavior of MG is one of the recent development in control of MGs [8]. Similarly, adaptive control strategies of the planners of MG the capability of making it intelligent on many levels, namely primary, secondary, and tertiary [9 - 11]. The integrating these control strategies helps MGs to achieve operational efficiency, reduce GHG, and enhance energy access.

At the core of successful MG planning and operation lies the application of robust control strategies. These strategies are essential for managing the inherent complexities of MGs, including the variability of renewable energy generation, fluctuating demand patterns, and interactions with the main grid. They ensure that MGs can operate sustainably, efficiently, and reliably while minimizing environmental impacts.

## TYPES AND ARCHITECTURE OF MICROGRIDS

There various types of MGs that are currently in use for different applications. In fact, classifications of MGs have mainly been based on the type of electrical signals, configurations and resources types.

## CHAPTER 7

# Development of an Automated Poultry House Temperature Control System Using an Optimization Approach Based on a Proportional Integral Derivative Controller

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**Abstract:** Temperature is one of the vital factors to be taken into account for optimal production of poultry products intended for human consumption. The Fuzzy-Proportional Integral Derivative (Fuzzy-PID) method that is being used to regulate poultry houses within the birds' thermal zone is time-consuming and needs constant monitoring. This study thus designed a system based on a Proportional Integral Derivative (PID) controller with Particle Swarm Optimisation (PSO) to tune the temperature of a poultry farm automatically. A PSO-based automatic PID controller was designed in which the PSO algorithm was embedded in the PID structure. The PSO algorithm tuned the parameters of the PID controller to achieve maximum control efficacy. PID controller parameter optimization was aimed at improving three specific aspects: proportional gain (Kp), integral time (Ki), and derivative time (Kd). Simulation of the controller designed was carried out with MATLAB (R2018a). For the validation of the obtained results, a performance analysis of the proposed methodology was also conducted in comparison to the proposed Fuzzy-PID approach on parameters such as rise time, settling time, minimum settling value, maximum settling value, peak time, and overshoot. The simulation results obtained included the rise time, settling time, settling min, settling max, peak time, and percentage overshoot for the PSO-based PID controller as 0.330, 5.131, 18.042, 27.254, 1.778 s, and 14.457%, respectively. The values for Fuzzy-PID were 0.332, 5.364, 18.035, 27.971, 1.681s s and 15.316%, respectively. A PSO-based PID controller brought improved performance in poultry house temperature control than traditional Fuzzy-PID control did. PSO-based PID is applicable in the temperature control of poultry houses and other similar environments.

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**Keywords:** Fuzzy-PID, Overshoot, Peak time, PSO-PID controller, Rise time, Settling max, Settling min, Settling time, Temperature.

## INTRODUCTION

Automation plays an expanding role throughout modern agricultural practices because it supports sustainable agricultural approaches. Developing economic growth significantly depends on integrated poultry systems that contribute to the success of agricultural economies [1]. Commercial bird breeding operations include the production of domesticated animals like chickens, ducks, turkeys and geese. Environmental conditions for poultry growth are improved through special construction structures made for this purpose. The residence environment of animals directly affects the chicken's health status [2]. Poultry farming productivity, as well as its feasibility, is strongly influenced by temperature impacts that reduce bird health status according to scientific findings. High temperatures, which combine with humid conditions, generate significant stress on birds that diminishes their performance measures [3]. The delivery of suitable temperatures necessary for the best development serves as the essential requirement for achieving profitable agricultural cultivation. The farmers experience heavy financial losses because meteorological forecasts prove inaccurate, combined with conventional agricultural techniques that are not effective [4].

The microclimatic conditions of poultry houses depend on temperature, humidity, and the amount of ammonia, together with dust particles within the facility [5]. Controlling the temperature of poultry houses within poultry bird thermal neutral zones proves essential to decrease deaths while enhancing production [6], because varying climatic conditions can create unideal high or low temperatures and relative humidity. Current methods to regulate poultry house temperatures inside the thermal neutral bird zone demand extensive time commitment while demanding constant supervision [7]. The research discovered that higher concentrations of ammonia damage bird immune systems and worsen their respiratory diseases [8]. Buildings should use ventilation to prevent unfavourable conditions that occur when relative humidity reaches above 70% [5].

According to scientific investigations, high relative humidity serves as a factor that helps diseases spread among poultry animals. Birds that experience either hot or cold environmental conditions need increased energy to maintain their body temperature [9]. The correct temperature range for bird body functions exists between 39.4°C and 40°C. Adult birds preserve their body temperature within their thermal neutral zone, which exists between 18°C and 23.9°C according to a study [10], but [8] adult broilers exist between 26°C and to 28°C. The temperature inside the poultry house, which falls under the birds' thermal neutral zone, forces birds to divert diet-based energy toward heat generation instead of growth. Heat production outside the thermal neutral zone causes decreased feed conversion efficiency since birds lose heat through external means [11]. The main farming systems require an innovative, efficient technological solution to boost productivity and profitability, as well as sustainability.

Research has adopted three control approaches: adaptive control, sliding mode control, and fuzzy control. The Proportional Integral Derivative (PID) controller stands as the main choice for widespread application because it features a simple structure that delivers stable performance across different operating conditions, even though alternative techniques introduce complexities and added computational costs. The initial process of setting PID controller gains becomes challenging due to the inherent characteristics of high order, time delay, and nonlinearity [12, 13]. PID controllers are traditionally modified using the Ziegler–Nichols procedure. Several practical implementations benefit from this method, yet its performance results in excessive overshooting [14]. Through an optimization method using the PSO algorithm, the PID controller parameters can be optimized to achieve superior performance compared to traditional PID operation. PSO optimization was selected because it contains various beneficial features, which include easy design, uncomplicated implementation, and robust control parameters using a few elements with minimum memory consumption, fast computational ability, and the ability to handle non-linear continuous optimizations and generate many distinct solutions while operating periodically [15, 16].

Within the field of swarm intelligence algorithms, PSO functions to determine optimized solutions from search areas and predicts collective social behaviour under defined objectives. As opposed to other stochastic approaches, the PSO technique yields results of high quality through faster execution and maintains stable convergence patterns. Every item inside the PSO algorithm maintains a swarm structure, which represents possible solutions. The search procedure takes place in a multi-dimensional space that allows controlled modifications of the position of each particle built from individual knowledge together with neighbour-based experiences. PSO features two principal versions, which include gbest PSO as well as lbest PSO [17, 18]. As described in a study [19], the PID controller operates as a basic control feedback loop design with maximum adjustment capabilities. Industrial organizations use this process as the prime choice for their control applications. The three core control variables consist of the Proportional constant (P), which adjusts the controller output while setting desired points through its function. The steady-state error of systems can be eliminated while the steady-state response improves through the use of the

## CHAPTER 8

# Investigation of Interrelationship between Variables Affecting Industry 4.0 Adoption in Manufacturing Industry

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**Abstract:** As sustainability becomes increasingly important in business management, industrial organizations must adopt appropriate technologies to remain competitive in the market. This has contributed to the introduction of Industry 4.0 (Id4.0) in industrial organisations. While most literature emphasises the benefits of Id4.0, there remains a need for a clear understanding of its implementation factors to facilitate a smooth transition for manufacturing companies in emerging economies. Consequently, this study investigates the interrelationships between these implementation factors to support the achievement of sustainable manufacturing. To achieve this, the study conducted a descriptive analysis to determine the implementation rate of Id4.0. The findings revealed that approximately 70% of manufacturing companies in the study area had adopted Id4.0. The proposed hypotheses were then tested using a partial least squares structural equation model in SmartPLS 3. Of the ten hypotheses, six were accepted, and four were rejected. This may be attributed to industrial norms, such as prioritising certain implementation factors over others, or a lack of effective integration of the strategies associated with these factors. Consequently, the findings of this study could help manufacturing industries in emerging economies accelerate their adoption of Id4.0, enhance competitiveness, and achieve long-term sustainability.

**Keywords:** Implementation factors, Industry 4.0, Partial least squares structural equation method, Sustainable manufacturing, Triple Bottom Line (TBL) framework.

## INTRODUCTION

According to Bag *et al*. [1] and Ramirez-Peña *et al.* [2], manufacturing organisations in previous industrial revolutions were primarily concerned with achieving economic gains, while largely neglecting the other two dimensions of

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sustainability—social and environmental. Consequently, governments and various environmental bodies are now exerting considerable pressure on manufacturers to comply with stringent environmental and social standards. To meet these requirements, manufacturing organisations must align their approach to production and service delivery with the Triple Bottom Line (TBL) framework, which is defined as follows:

i. Producing products that yield a higher return on investment for improved economic gains;
ii. Developing environmentally friendly products to help mitigate the effects of environmental degradation; and
iii. Cultivating an innovative workplace culture that encourages creativity, learning, and collaboration [3].

This will strengthen the manufacturing organisation's ability to survive in today's fiercely competitive business environment. Production and operations management are among the most fascinating aspects of the manufacturing sector, which is why there is a need for a technique that provides industry players with clear insights into their processes and systems. Such insights can help them achieve their goals of delivering eco-friendly, socially responsible products or services while also enhancing profitability.

In order to make this a reality, manufacturers are showing growing interest in Industry 4.0 (Id4.0), which encompasses automation and control concepts that enable autonomous decision-making, real-time monitoring, and adaptive production processes [4]. Id4.0 has the potential to enhance the productivity and agility of manufacturing processes, while creating value through innovative services, improving product quality, promoting sustainability, fostering interconnectivity, and enabling effective stakeholder collaboration to meet consumer demand for manufactured goods [5]. However, the key challenge lies in adapting to this novel concept. According to a study [6], both large and small-t--medium-sized enterprises have found it relatively easy to adopt Id4.0 and its associated technologies, particularly in developed nations, due to the availability of the basic infrastructure needed for implementation. Nonetheless, as noted in the literature, there is still no conclusive evidence that Id4.0 has been implemented in practice [7]. Furthermore, when evidence of implementation is provided, as in [8] and [9], it largely consists of pilot studies with minimal overall business impact. This has prompted the present study to investigate the interrelationships between variables influencing Industry 4.0 (Id4.0) adoption in the manufacturing sector. While the key success factors for Id4.0 adoption in manufacturing enterprises have been described in previous research, few studies, such as [10 - 14], have explored how the drivers of Id4.0 interact to achieve sustainability in the manufacturing industry. The limited number of such studies highlights the need for further assessment of these interrelationships to empirically validate earlier findings, specifically from an emerging economy. Accordingly, this study seeks to examine the correlations between variables influencing Id4.0 adoption in manufacturing organisations within the Ado/Odo-Ota industrial hub of Ogun State, Nigeria, to foster sustainability. Transitioning to Id4.0 for sustainable manufacturing will require a thorough understanding of the critical implementation variables and their relationships.

## LITERATURE REVIEW

The dynamic and ever-evolving demands of customers have been a fundamental driver of industrial revolutions throughout history, a trend reflected in today's rapidly changing business climate. In this context, making industrial processes sustainable, *i.e*., balancing people’s welfare, environmental responsibility, and organisational profitability, has become increasingly important for manufacturers [15]. Belaud *et al*. [16] define sustainability as the capacity to meet present needs without compromising the ability of future generations to meet their own needs. With this in mind, and to enhance manufacturing productivity while avoiding harm to the environment and social well-being, the German government introduced Id4.0 in 2011, a digitalisation initiative [17].

### Industry 4.0 and Its Technologies

According to Hermann *et al*. [18], the term Id4.0 refers to a collection of concepts and technologies related to value chain organisation. In Id4.0’s modularly designed smart, automated factories, Cyber-Physical Systems (CPS) monitor physical processes, create a virtual representation of the real world, and enable decentralised operations. These CPS interact and collaborate in real time with humans *via* the Internet of Things (IoT). The IoT, which facilitates connections between devices, products, systems, and people, forms the foundation of Id4.0, where the integration of smart products into both digital and physical workflows is a defining characteristic [19].

As noted by Surah *et al*. [20], Santos *et al*. [21], and Schmidt *et al*. [22], Id4.0 combines new technical components and guiding principles to develop concepts that promote vertical and horizontal integration across the entire value chain. Horizontal integration involves connecting various systems and enabling communication between them at all stages of the value chain. This includes relationships between production, design, logistics, and other departments, both within and across organisations. Vertical integration, on the other hand, refers to the merging of hierarchically structured systems by consolidating data from

CHAPTER 9

# Development of Smart Voltage Level Control for a Hybrid Power Generating System

**Ayodele Samuel Onawumi**[1,*], **Nathaniel Abidemi Akinrinade**[2], **Emmanuel Olayinka Sangotayo**[3], **Oluwole John Famoriji**[4] and **Moses Abiodun Olojede**[3]

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**Abstract:** Hybridized power-generating systems have emerged as more and more popular in recent years due to their potential to offer dependable and sustainable energy. Hybrid power systems, which integrate solar, a generator, and a mains supply, are increasingly used for sustainable energy solutions. However, voltage fluctuations from those sources can threaten equipment protection and system stability. This study introduces a voltage regulation system designed to stabilize these fluctuations in hybrid setups. The system incorporates step-down transformers, rectification circuits, and a microcontroller to monitor input voltages and select the appropriate energy sources. Tested under each overvoltage and under-voltage condition, the system effectively stabilized the output voltage, ensuring equipment protection. The outcomes demonstrated stability despite significant fluctuations with the mains supply (±60V, stability rating of 40%) and moderate fluctuations in generators without AVR (±10V, rating of 90%). In contrast, generators equipped with AVR (±2V, rating of 98%) and advanced inverters (±1V, rating of 99%) maintained stable output, highlighting the system`s capacity to control voltage instability in hybrid power systems efficiently. Finally, the outcomes obtained in this work are motivating and sufficient for industrial implementation in the automotive, manufacturing, and smart grid sectors.

**Keywords:** Appliance protection, Hybrid power system, Microcontroller, Sustainable energy, Voltage regulation.

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## INTRODUCTION

The international transition toward sustainable power systems has highlighted the pressing need for hybridized power systems that combine renewable sources such as solar with conventional sources, including generators and grid electricity [1]. These structures are especially essential in areas with unreliable electricity supply, ensuring a non-stop power supply. Nigeria, for instance, is predicated closely on thermal and hydropower sources for its electricity era, with fossil fuels, specifically natural gas, accounting for 86% of the country`s power production, whilst hydropower contributes the remainder [2]. Despite having 23 power plants connected to the country-wide grid and a combined installed capacity of about 11,165 MW, the country faces significant challenges meeting power demand due to ageing infrastructure, transmission inefficiencies, and frequent outages [3]. Reliable power delivery is vital not only for essential home purposes but also for critical infrastructure, including healthcare, transportation, and communication systems [3, 4]. The lack of reliable power undermines critical services, exacerbating social vulnerabilities and hindering improvement. In regions like Southwestern Nigeria, many households are forced to rely on inefficient power sources, including biomass for lighting and cooking, due to limited access to grid power. This dependence on unstable power supplies requires pressing, sustainable power solutions to address the annoying situations. The need for renewable energy is further emphasised by the valuable resource of global efforts to promote sustainable development and mitigate climate change [5].

Hybrid energy structures have emerged as a promising choice to address these challenges, specifically in regions where extending the country-wide grid is economically or logistically unfeasible. By combining several energy assets, hybrid structures can capitalize on the benefits of renewables while mitigating their intermittency with reliable backups, such as turbines or grid energy [6]. These systems have received traction due to their potential to enhance energy security, enhance overall performance, and reduce dependence on fossil fuels. Recent advances in renewable technologies, coupled with improvements in hybrid device design, have enabled combining multiple power sources into cohesive devices that address multiple power needs [7]. Studies have demonstrated that hybrid systems are particularly beneficial for rural and underserved communities, providing reliable energy to households, businesses, and public facilities [8]. Researchers have moreover confirmed the effectiveness of hybrid power management across several applications, from embedded sensor networks to electric-powered vehicles, where coordinated energy sourcing improves the overall performance and reliability of fundamental tools [9].

Despite their promise, hybrid structures face significant technical challenges, particularly in maintaining voltage stability. Voltage fluctuations are not unusual causes of trouble in hybrid setups due to variations in the availability of renewable energy, adjustments in load demand, and inconsistencies in generator or grid output [10]. Without powerful voltage regulation, hybrid systems can also experience inefficiencies, reduced lifespan of components, or damage to sensitive appliances. Maintaining a stable voltage is vital to ensuring stable device operation, optimizing power use, and preserving long-term device performance. Voltage regulation becomes even more crucial in systems serving rural or remote communities, where protection sources are limited and downtime can have significant socio-financial implications [11].

To cope with those challenges, voltage level controllers have been developed to ensure strong outputs regardless of the form of the input sources. These controllers monitor and adjust the voltage in real time, preventing overvoltage or under-voltage situations that could disrupt system operations or damage associated equipment. Advanced voltage law technologies, which include DC-link controllers, voltage source inverters, and multilevel power converters, were widely studied for their ability to enhance the general overall performance of hybrid energy systems [12]. Additionally, records logging skills protected in contemporary-day controllers provide valuable insights into the gadget`s usual overall performance, permitting well-timed interventions and long-term length optimization. By recording crucial parameters, including input voltage, output stability, and environmental factors such as daylight depth and temperature, these systems can enable positive, reliable, and efficient operations [13].

The development of a strong voltage regulation system for hybridized power setups is critical for harnessing their full potential. Such structures must stabilize fluctuating inputs, prioritize renewable energy sources, and seamlessly switch power supplies based on availability and usability.

## MATERIALS AND METHODS

The voltage regulation system was designed for a hybrid power setup comprising solar panels, a generator, and mains electricity (grid). Its key functionalities include stabilizing the output voltage, prioritizing renewable energy sources, and protecting appliances from excessive voltage. A microcontroller (Arduino Mega) serves as the crucial processing unit, imposing analog-to-digital conversion (ADC) to monitor voltages in real time and make selections based on predefined thresholds. The system additionally integrates real-time record logging *via* a GPRS module, which transmits operational data to a remote SQL server *via* PHP scripts for evaluation and monitoring.

## CHAPTER 10

# Hybridized Energy Systems: Optimization Strategies for Sustainable Power Generation in Developing Regions

**Ayodele Samuel Onawumi**[1,*], **Nathaniel Abidemi Akinrinade**[2], **Emmanuel Olayinka Sangotayo**[3], **Oluwole John Famoriji**[4] and **Moses Abiodun Olojede**[3]

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**Abstract:** Access to stable power remains a major challenge in areas with unreliable power grids and frequent outages. This study examines a hybrid power system integrating solar panels, batteries, and a generator, managed by an Arduino Mega microcontroller to optimize energy use. The system prioritizes solar energy because it is the primary supply, automatically switching to backups when necessary, ensuring an uninterrupted power supply. Real-time monitoring of voltage, temperature, and sunlight intensity allows the machine to make dynamic adjustments for optimal performance. Testing was carried out on a 1030Wh load, demonstrating a solid battery voltage of 12.35V at some point during an excessively sunny day, Day 4, with 730 $W/m^2$solar intensity. Generator utilization substantially decreased to a mean of just 2 hours per day during periods of grid instability. The effects additionally confirmed a clear correlation between sunlight intensity and battery performance, highlighting the system`s capacity to harness solar energy effectively. This hybrid power system no longer guarantees constant energy availability but also minimizes reliance on non-renewable power sources, lowering environmental impact. It offers a sensible solution for energy-poor areas, presenting a reliable, sustainable, and cost-effective power alternative. These findings underscore the ability of hybridized energy systems with advanced controls to remodel energy access in developing areas.

**Keywords:** Hybrid energy systems, Solar power optimization, Sustainable energy solutions, Voltage control.

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## INTRODUCTION

The hybrid system achieved advanced overall performance through the combination of solar power with a backup power source, ensuring a reliable power supply. Access to reliable electricity is an exceptional challenge in many rapidly growing areas, where frequent power outages and unreliable grid infrastructure limit economic growth and everyday activities [1]. In response to this, hybridized electricity systems, which combine renewable electricity sources like solar with conventional electricity generation technologies, have emerged as a probable method to improve electricity availability and sustainability in these areas [2]. These systems now do not provide a consistent supply of power but also help reduce reliance on fossil fuels, thereby contributing to environmental sustainability [3].

The integration of solar energy into hybrid power systems has been particularly promising because it provides a renewable and significant electricity source. However, the intermittent nature of solar electricity, due to factors such as climate and time of day, necessitates the use of backup power sources, such as batteries or diesel generators [4]. Hybridized systems that combine solar power with these backup sources offer a more resilient and robust energy supply than relying on a single power source [4]. In growing areas, such structures can address the critical need for reliable power even whilst minimizing the environmental impact of conventional electricity technology [5]. Effective device optimization is vital for the fulfillment of hybridized electricity structures. Optimizing the usage of solar energy at the same time as coping with the aggregate of backup power sources ensures green energy use and reduces the need for costly, environmentally risky gas consumption [6]. For instance, power storage systems, such as batteries, permit more energy generated during some unspecified daytime in the future to be stored for later use, ensuring non-foreseeable electricity availability even if solar technology is low [7]. Additionally, incorporating smart control systems into hybrid electricity systems can optimize electricity distribution, prioritize renewable energy use, and reduce reliance on backup generators [8].

This study explores strategies for optimizing hybridized electricity systems in growing areas. Specifically, it specializes in a device that combines solar panels, batteries, and generators to provide reliable, sustainable electricity. The device`s optimization ensures maximum use of solar power and decreases generator usage, contributing to economic and environmental benefits. This method is specifically relevant in rural and off-grid areas in which conventional electricity infrastructure is regularly restricted or unavailable [9].

The format and findings of a hybridized electricity device highlight the capability for renewable energy integration to address electricity shortages in developing areas [10]. Additionally, targets illustrate how powerful optimization techniques can enhance the reliability and sustainability of hybrid energy structures, even by reducing operational prices and environmental effects [11]. The consequences have great implications for energy coverage and infrastructure development, specifically in areas with restricted access to conventional energy grids.

## MATERIALS AND METHODS

### Research Design and Approach

The hybridized system developed incorporates three principal sources of energy: the grid, solar, and generator systems. The objective was to develop a hybrid power system capable of maintaining stable voltage under various environmental conditions. The layout combined solar panels with grid and generator backups, prioritizing solar power as the primary energy source. The technique involved analyzing present systems, figuring out key gaps, and developing an innovative, integrated system tailor-made to deal with real global energy challenges.

### System Development

The generalized block diagram in Fig. (**1**) offers an overarching illustration of the hybridized power system, highlighting the primary energy sources, management mechanisms, and outputs. This diagram simplifies the system`s structure into key practical blocks:

- **Input Sources**: Solar panels, mains electricity, and a backup generator serve as the system's energy inputs, ensuring multiple power options to maintain supply under various conditions.
- **Energy Storage**: Batteries act as the central energy storage unit, storing excess solar power for use during periods of low sunlight or power outages.
- **Control Unit**: The microcontroller coordinates the operation of the Automated Transfer Switch (ATS), sensor modules, and statistics logging mechanisms, permitting real-time tracking and green energy management.
- **Output to Load**: Stabilized power is delivered to connected appliances, ensuring consistent voltage and reliability.

The exact circuit layout is illustrated in Fig. (**2**)**,** highlighting the interconnection of centre components.

## CHAPTER 11

# A Neuro-Optimization Technique for Dynamic Modelling of Small-Weight Electric Vehicles: Leveraging Artificial Intelligence for Enhanced Design

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**Abstract:** This study explores the integration of artificial intelligence techniques, specifically artificial neural networks, in the design optimization of electric vehicles. Using data from MATLAB Simulink simulations, three different training algorithms were employed to model dynamic vehicle performance metrics, including speed, revolutions per minute, and distance, under varying forces. The results indicate that AI significantly mitigates common design challenges, including speed, memory usage, and accuracy, in traditional design systems. Notably, the Levenberg-Marquardt algorithm excelled, yielding a Coefficient of Multiple Determination (CMD) of 0.9882 and a Variance Accounted For (VAF) of 97.82% on the test dataset. These outcomes show that AI can substantially reduce the need for repetitive, computationally heavy simulations, marking a pivotal advancement in the design and development processes of EVs.

**Keywords:** Artificial Intelligence (AI), Electric Vehicles (EVs), Energy efficiency, Optimization algorithms, Soft-computing.

## INTRODUCTION

Land vehicles have been a solution adopted by mankind for moving from one point to another for the delivery of humans, goods, and services. This has led the world into an era of fossil fuel use, in which variants of petroleum products power vehicle engines. However, the adverse effects of the continuous use of fossil fuel products on the environment are beginning to open researchers' eyes to other environmentally friendly mobility solutions. The development of Electric Vehicles (EVs) is one of such solutions that guarantee significantly reduced

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carbon emissions and has therefore been on the increase in recent years [1 - 3]. These EVs derive power from batteries rather than relying on Petroleum Motor Spirit (PMS).

The recent increase in the adoption and patronage of electric vehicles is largely due to their environmental friendliness, as environmentally friendly innovations are the order of the day. Electric vehicles are mainly energy efficient because they do not operate on the principle of combustion and heat like most internal combustion engines. In addition to their environmental friendliness and energy efficiency, some electric vehicle users also power their homes with energy generated by their electric vehicles, especially for non-heavy equipment. The development of electric vehicles is therefore seen as a crucial tool in the quest for reaching the millennial development goal on clean energy, the environment and renewable energy. This optimization requirement has posed a challenge for engineers and manufacturers as they seek to balance weight, performance, and efficiency. Artificial Intelligence (AI) techniques have therefore proven handy for this purpose and many others because of their unique qualities. Some of these intelligent approaches are Artificial Neural Networks (ANNs) for pattern matching and classification tasks [4 - 6], Fuzzy Inference Systems (FIS) for integrating human linguistic qualities into computing [7 - 9], and Genetic Algorithms [10, 11] for optimization tasks. The main benefit of these techniques lies in their speed, retrainability, low computational requirements, ability to handle complex nonlinear problems, and relatively simple mathematical basis. Artificial Neural Networks, in particular, are finding increasing applications in EV design [12 - 16], and this trend is on the rise because they significantly reduce design time compared to traditional design techniques such as MATLAB, Simulink, and Simscape, which are considered computationally intensive.

Apart from the design stage, artificial intelligence has recently found applications in training electric vehicles for self-driving. Wherein these intelligence solutions harvest input from cameras, sensors and actuators as input into their architectures and produce outputs based on the training they have had. The results obtained with these intelligent systems have been impressive so far. Further underlining the growing applicability of soft computing and intelligent techniques in different domains of electric vehicle designs and applications.

In this article, several neural network algorithms were employed to train an optimized ANN architecture to model a lightweight electric vehicle, using training data extracted from a MATLAB Simulink design based on first-principles differential equations and control equations. The cross-evaluation of performance under different operating conditions was thereafter performed. This work, therefore, stands as a viable technique for rapidly analyzing the performance of electric vehicles during design, a ready tool for designers to avoid the time and computational resource challenges that come with repetitive, laborious simulations.

## METHODS

### Electric Vehicle Modelling and Simulation

The production of electric vehicles entails critical simulations with specialized software, many of which are based on the mathematical models of EVs under different conditions.

The equations modelling the electric vehicle portrayed in Fig. (**1**)are considered dynamic because they attempt to describe the system at every instantaneous time t. The modelling aims to determine, using differential equations, the speed, velocity, and distance covered in response to the application of force F.

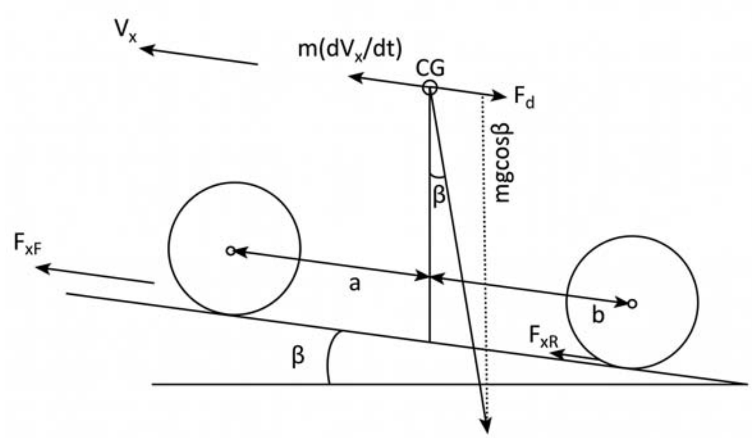


**Fig. (1).** EV parameters in relation to the centre of gravity and inclination.

It is known that the force F can be expressed as [17]:

$$F = ma = m\frac{dV}{dt} \tag{1}$$

The total force Fx as shown in Fig. (**1**) can be written as:

$$F_x = F_{xR} = m\frac{dV_x}{dt} + F_d + mgsin(\beta) \tag{2}$$

# CHAPTER 12

# Performance Sensitivity of Extreme Learning Machine (ELM) for Correlation-Based Feature Selection in Reservoir Characterisation

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**Abstract:** Permeability measures the ease with which oil and gas move through permeable rocks and has been of great significance in reservoir characterisation. The amount of recoverable oil in a reservoir, the rate of flow, the scale of oil, as well as the gas present in a reservoir, are among the crucial features that can be well understood with knowledge of permeability. Despite this significance, experimental measurement of permeability is restricted to the use of sophisticated equipment in different oil and gas fields. The existing theoretical and computational methods for addressing these challenges include the development of statistical techniques, empirical formulas, and computational intelligence-based models. This research aims to improve the performance of the Extreme Learning Machine (ELM) as a computational intelligence method for reservoir characterization through a correlation-based feature selection approach. ELM was developed and validated using an actual industrial dataset acquired during petroleum exploration from three distinct oil wells situated in a Middle Eastern oil and gas field. The researchers developed two models for each well, including ELM-NF, which employs all available descriptors, and ELM-SF, which employs fewer features that are highly correlated with the experimentally obtained permeability. Each of the two models has five sub-models. The developed ELM-SF performed better than ELM-NF. The outstanding performance of the proposed correlation-based feature selection method has significantly improved the performance of intelligent algorithms with reduced computational complexity and time, which would strengthen the exploration capacity of the oil and gas field and address the key challenges experienced in the process of oil and gas exploration.

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**Keywords:** Core analysis, Extreme learning Machine, Hydrocarbon reservoir, Permeability, Reservoir Characterization (RC).

## INTRODUCTION

Permeability is an important characteristic of rock that allows for the easy flow of oil and gas during exploration. Permeability stands out as a crucial property in underground reservoirs containing hydrocarbons. Traditional techniques such as core analysis and well testing are critical to understand subsurface formations and support numerical modelling to achieve reservoir characterization [1]. Permeability, typically evaluated through core analysis and well test data [2], serves as an indicator of the interconnectedness of rock pores and offers a measure of the fluidity of oil and gas through the rock interstices [3]. Throughout the well's life cycle, it is crucial to collect information that precisely characterises the reservoir.

Reservoir Characterization (RC) is the process of describing all the features of the reservoir in high-resolution models. RC develops high-performance models to optimize hydrocarbon extraction and manage reservoirs excellently [4]. Generally, there are three primary methods for determining permeability: computational intelligence, empirical, and statistical approaches [5]. The frequently used method is the empirical approach, which involves directly measuring permeability from samples collected in the exploration field. The empirical method involves a lot of cost. It takes much time when applied to large samples of data and requires sophisticated equipment [5]. Another method commonly employed to address permeability-related issues is the use of statistical approaches. This method involves employing regression analysis to predict and calculate the degree of permeability. This is done by using many parameters to describe the reservoir's permeability, and a linear model can then be generated from the logging data. According to a study [3], permeability determination methods are statistical, prone to instability, and exhibit narrower distributions. A paper [6] describes permeability averaging as a weighted-average technique that can represent combined layers in various applications such as geotechnical and petroleum engineering modelling.

Computational Intelligence Techniques (CITs) are widely accepted due to their successes in solving several real-world problems. It has been successfully applied to solve many real-life problems, such as face detection/recognition in manufacturing industries, speech-related applications, determining material properties, and the medical industry, among others. These successes have led to widespread acceptance of CIT as a leading tool for permeability prediction in the petroleum industry.

Some of the early works used Artificial Neural Networks (ANN) for permeability prediction, including many of their hybrids, such as a combination of fuzzy logic and functional network with ANN. Despite the progress made in the use of ANN for permeability prediction, there are lots of setbacks to the technique. A major technique resulting from this improvement is support vector regression SVR which also has a poor performance with large data, and Fuzzy logic has high complexity [7].

ELM is a relatively recent approach to training Single-Layer Feedforward Neural Networks (SLFNNs), offering an explicitly provided solution [8]. The ELM is widely employed in batch, sequential, and incremental learning due to its fast and efficient learning speed, rapid convergence, robust generalisation, and straightforward implementation [9]. Compared to a Conventional Neural Network (CNN), ELM mitigates the problems of slow training speed and overfitting. ELM applies empirical risk minimization theory with a single iteration learning process, bypassing the need for multiple iterations and local minimization. The algorithm offers advantages such as improved generalization, robustness, controllability, and a rapid learning rate, making it applicable across various fields and scenarios [10]. Hence, in this research, a computational intelligence method is deployed to develop a predictive model using correlation-based future selection and the Extreme Learning Machine algorithm as the classifier.

## DESCRIPTION OF EXTREME LEARNING MACHINE (ELM) TECHNIQUES

ELM is a Machine Learning (ML) algorithm belonging to the Feedforward Neural Networks (FNN) family. It was an efficient learning algorithm introduced for training Single-hidden-Layer Neural Networks (SLFNs). ELM differs from traditional gradient-based learning methods by using a random initialization for the hidden-layer weights and directly calculating the output-layer weights analytically [11 - 13].

In reservoir engineering and characterization, the ELM has the capability to model and analyze various aspects of reservoir properties. The specific equation for using ELM in reservoir characterization depends on the particular application and the reservoir property being studied [14]. In a scenario where ELM is used to estimate a reservoir property, such as porosity or permeability, based on a set of input features (X) related to the reservoir. The ELM equation is given as equation 1.

$$Y = \beta * H(X) \quad \mathbf{(1)}$$

# CHAPTER 13

# Development of an Automated Vehicle Tracking and Accidents Alert System

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**Abstract:** In this study, an automated vehicle tracking and an accident alert system are designed and implemented for rescue operations at accident scenes. It comprises a camera, an MQ2 gas sensor and an accelerometer for quick and effective response. The MQ2 gas sensor is used in the sensing of the flammable gases in the layers, which will show signs of fire or fuel leakage. Accelerometers were used to record impact forces and successfully distinguish collisions by comparing the data with normal accelerometer readings. Should a powerful collision be identified, the system then alerts the car's corresponding services to its location. In the performance evaluation of the developed system, the findings revealed that the MQ2 gas sensor is capable of identifying the concentration of gases beyond the generally recommended values, which in turn generated alarms. The integration of these sensors in one system helped to show the increase in the accuracy of detecting accidents and starting an immediate response. Therefore, the vehicle tracking and accident alert system is useful in reinforcing car safety and emergency management.

**Keywords:** Accelerometer, Accident alert system, Automated vehicle tracking, MQ2 gas sensor.

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## INTRODUCTION

A localisation system is the same as a tracking system. It is a device made to track an object or a person's location over time. It records and displays location data continuously or almost continuously [1]. Some of the services include: Fleet management and security are among the services offered by the car tracking systems. On-board navigation systems, as described by Misra and Enge [2], use establishments that include GPS and other forms of navigation establishments, depending on satellite and ground station establishments to determine the position of a vehicle. Current technologies that enable tracking of cars and identification of any location across the globe normally employ GPS as the tracking medium, and there are other types of car tracking technologies that are also available [3]. Again, the tracking data may be exported and saved in a computer once a device is affixed to the car for further analysis [4]. There are a few important points to recall: This innovative device, which has several advantages and is rather popular among the owners of luxurious automobiles, allows the owners to locate their vehicles at all times. In the case of software and internet facilities, the information gathered is in the form of electronic maps or Short Messaging Service, which reflect position coordinates. According to El-Rabbany [5], these systems may be used by owners to locate their assets because they work on satellite signals, which are capable of pinpointing the exact location of any moving object, including automobiles.

In addition to improving the efficiency of logistics processes, the technological vehicle-tracking system, using GPS and other tools, enhances safe driving behavior [6]. Accident Alert Systems (AAS) enhance data collection for traffic safety initiatives by promptly identifying accidents and facilitating prompt emergency responses. According to Prabhu and Balaji [7], these systems are designed to identify accidents quickly and transmit basic data, such as the location, time, and angle of the incident, to specified contacts, such as emergency dispatch centres and next of kin, in a matter of seconds.

The "Vehicle Tracking and Accident Alert System using GPS and GSM Technology" project addresses the needs of modern vehicle fleet management; it is a versatile system that benefits companies managing fleets as well as individuals looking to monitor their assets and improve safety. GPS coordinates were first transmitted *via* SMS through GPS and GSM integration [8]. The addition of GPRS technology enabled sending location coordinates to a remote server, allowing web-based tracking from any connected computer [8]. The precise location of a vehicle or asset is determined by a GPS tracking unit attached to it [2]. GPS receivers on Earth calculate longitude, latitude, and altitude by measuring the time radio signals from multiple satellites.

By assisting field sales representatives in finding sites and organizing their schedules, vehicle tracking is helpful for asset management and increasing productivity. The majority of systems employ GPS as their primary tracking tool and rely on satellite or cellular connections to send the vehicle's position data to the authorised user. Fleet managers, employers, and parents frequently utilise these systems for navigation, safety, and monitoring driving behaviour, as well as to deter theft.

The existing vehicle tracking systems are not able to support the effective detection of accidents in a timely manner and alert the emergency response departments in time hence, the delay makes response slower and death rates higher since too much time is lost in searching for where the accident occurrences have taken place. This requires that a suitable system be put in place to monitor the parameters of vehicles at all times, detect the occurrence of an accident automatically and notify the emergency services and contacts in time.

The aim of this project is to develop a vehicle tracking and accident alert system using GPS and GSM Technology. The need to improve traffic safety and lower the death toll is what led to the development of a car tracking and accident alert system. The action request of the emergency service must be executed very quickly, considering the increasing congestion of traffic and the rate of road traffic accidents. The assistance is late because contemporary time tells them that the current system is not able to transmit appropriate, timely accident notices along with accurate location finding information. This project aims to improve life, reduce the time it takes for an emergency response to be made and assure fleet managers as well as vehicle owners by providing real-time tracking combined with instantaneous notification on accidents and fast response to the accidents.

Improvements in both software and hardware received a lot of attention in this attempt. Power supply units (which convert AC to DC) and the wiring that links modules to the microcontroller were among the key components of hardware development. A Google API was created, and microcontroller code was written as part of the software component to show the vehicles' whereabouts on Google Maps. Designing and implementing the VTAA (Vehicle Tracking and Accident Alert) system was the outcome of these components successfully combining.

The following are the significance of this study:

i. Enhanced Road Safety: The system also improves the issues of safety and security of the roads; this is through reporting of cases of accidents as they happen. It becomes easier to provide alerts to the emergency services, and this

# SUBJECT INDEX

## A



## B



## C



## D



## E




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## F



## G



## H



## I



## K



## L



## M

## N



## O



## P



## Q



## R

## S



## T



## U

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