IoT-Based Smart Home Automation for Optimized Power Management

By

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Certification

This is to certify that this project was carried out by **Abubakar Ahmed Olawale** with Matriculation Number **HND/23/COM/FT/0046** as part of the requirements for the award of Higher National Diploma (HND) in Computer Science.

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Dedication

The project is dedicated to the glory of Almighty God and my Parents

Acknowledgments

All praise is due to Almighty God for His grace, guidance, and strength throughout the course of this project. I am profoundly grateful to numerous individuals and institutions whose support and contributions were vital to the successful completion of this work.

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Table of Contents

Abstract

The growing energy demands in residential settings have highlighted the urgent need for intelligent power management systems that optimize electricity consumption without compromising convenience. This project presents an IoT-based smart home automation framework focused on optimized power management through real-time monitoring, intelligent scheduling, and remote appliance control. The system integrates smart sensors, actuators, and a Wi-Fi-enabled ***NodeMCU microcontroller****, which serves as the central hub for collecting and processing energy usage data. A custom-built Android application acts as the user interface, enabling homeowners to track energy consumption in real time, configure smart schedules, and control appliances remotely. The application supports device grouping, priority-based load management, and dynamic scheduling to reduce energy waste and shift loads away from peak periods. These features contribute to lower electricity bills and promote more sustainable energy usage patterns. Security is ensured through encrypted communication between the mobile application and the NodeMCU, along with secure user authentication protocols. The system is designed to be cost-effective and scalable, with support for cloud-based analytics and potential integration with renewable energy sources. Prototype testing demonstrated that the system effectively reduces unnecessary energy consumption and enhances the user's ability to manage power intelligently. This research contributes a practical and user-friendly solution to the field of smart home energy automation. It addresses key challenges such as real-time control, energy waste, peak load management, and user awareness, making it suitable for deployment in residential environments, especially in energy-conscious and resource-limited settings.*

Keywords

Smart Home Automation, Internet of Things (IoT), NodeMCU, Optimized Power Management, Load Scheduling, Android Application, Energy Efficiency, Real-Time Monitoring, Wi-Fi Communication

CHAPTER ONE
GENERAL INTRODUCTION

1.1 Background to the Study

In recent years, the rising global demand for electricity, coupled with escalating energy costs and environmental concerns, has placed immense pressure on efficient power utilization, particularly in residential sectors (Sharma et al., 2022). Traditional homes often lack systems that intelligently monitor or control electrical loads, leading to energy waste, high utility bills, and increased carbon footprints. The emergence of Internet of Things (IoT) technology offers transformative potential to address these challenges by enabling real-time monitoring, automation, and optimized energy management in smart homes (Sah et al., 2023).

Smart home automation integrates various IoT-enabled devices such as sensors, actuators, and microcontrollers that communicate over wireless networks to provide homeowners with convenient, remote control over appliances and energy consumption (Li et al., 2021). Notably, affordable microcontrollers like the NodeMCU provide accessible platforms for implementing cost-effective, scalable smart home solutions with optimized power management capabilities (Singh & Bhattacharya, 2023).

Recent research highlights the importance of integrating load scheduling, energy usage analytics, and real-time feedback to achieve significant reductions in energy consumption and peak load demands (Sharma et al., 2022; Zhang et al., 2024). For instance, intelligent scheduling of household appliances during off-peak hours has been shown to lower electricity costs while maintaining user comfort. Moreover, mobile platforms especially Android applications offer user-friendly interfaces for remote monitoring and control, increasing the practicality of smart home systems (Li et al., 2021).

Despite these advancements, challenges such as device interoperability, security vulnerabilities, and dependence on stable internet connections remain obstacles for widespread adoption, especially in developing regions with limited infrastructure (Sah et al., 2023). This study aims to develop an IoT-based smart home automation framework using NodeMCU and Wi-Fi technology to provide affordable, secure, and efficient optimized power management. The system will enable real-time energy monitoring, automated load control, and remote management via an Android app, thereby promoting energy savings and enhanced grid stability as shown in figure 1.1.

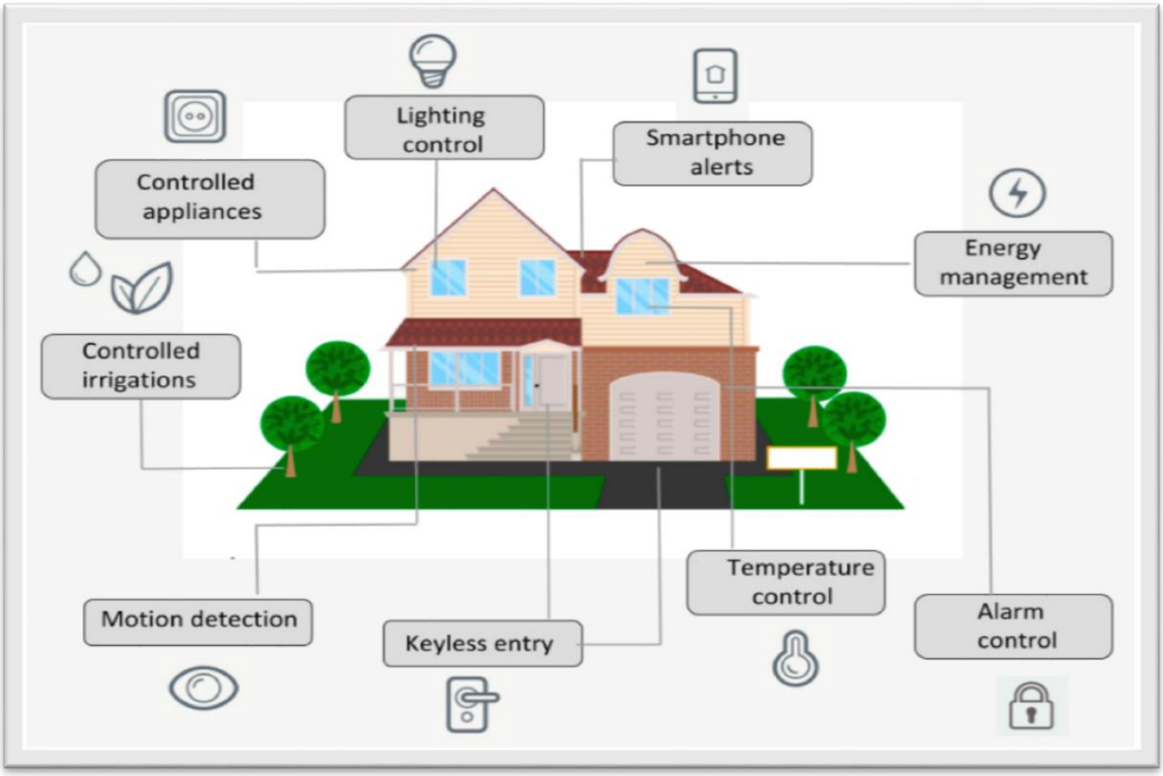

Figure 1.1: IoT-Based Smart Home Automation Architecture for Optimized Power Management

1.2 Statement of the Problems

Energy consumption in residential homes continues to rise due to increased reliance on electrical appliances and the absence of intelligent systems for managing electricity usage. This uncontrolled consumption results in excessive energy bills, inefficient power distribution, and strain on national grid systems, especially during peak demand periods. The inability to monitor, control, and schedule energy usage in real time presents a critical challenge that this research seeks to address (Sharma et al., 2022; Zhang et al., 2024).

Firstly, many households operate without any smart energy scheduling mechanisms. Appliances are frequently used without considering time-of-use tariffs or peak load periods, leading to higher energy costs and unnecessary pressure on the power supply system. According to Sah et al. (2023), the absence of automated load scheduling in smart homes significantly contributes to peak demand issues and power instability, particularly in developing regions.

Secondly, affordability and usability remain key barriers to the adoption of smart energy management solutions. Many commercial systems require proprietary hardware, complex installation, or paid cloud subscriptions, making them impractical for low- and middle-income households.

Lastly, issues related to cybersecurity and device interoperability hinder the effective deployment of home automation systems. Without secure communication protocols and standardization, systems are vulnerable to unauthorized access and data breaches. Singh and Bhattacharya (2023) highlight that weak authentication and fragmented standards are among the leading risks in current IoT-based smart home implementations.

This research is motivated by the need to address these problems through the development of a cost-effective, IoT-based smart home automation system using NodeMCU and Wi-Fi. The system is designed to support real-time energy monitoring, intelligent load scheduling, secure communication, and remote control via an Android mobile application. The proposed framework aims to optimize residential power usage, reduce electricity bills, and improve energy efficiency, particularly in environments with limited energy infrastructure (Patel et al., 2024; Kim & Lee, 2023).

1.3 Aim and Objectives

The aim of this study is to design and implement an IoT-based smart home automation system using NodeMCU and Wi-Fi technology, with a specific focus on optimized power management. The system seeks to provide real-time energy monitoring, intelligent load scheduling, and secure remote control of household appliances through an Android-based application, with the goal of reducing energy waste, improving power efficiency, and minimizing electricity costs in residential environments. The objectives are:

i. To design a cost-effective and scalable IoT-based smart home framework that enables the automation of household appliances for power optimization.

ii. To implement a real-time energy monitoring system using NodeMCU and sensors capable of tracking the consumption of individual electrical devices.
iii. To develop an Android mobile application that allows users to remotely control appliances, view energy consumption data, and schedule device operation based on priority and off-peak periods.
iv. To integrate an intelligent load scheduling algorithm that reduces peak load demand and improves overall energy efficiency.
v. To evaluate the system's performance in terms of power savings, responsiveness, and user accessibility in a residential environment.
vi. To ensure data security and communication integrity within the system by implementing user authentication and encrypted transmission protocols.

1.4 Significance of the Study

The significance of this study lies in its contribution to the advancement of intelligent power management in residential homes through the application of Internet of Things (IoT) technologies. With the continuous rise in energy consumption and electricity costs, there is a growing need for systems that can monitor, control, and optimize power usage efficiently. This project is designed to provide such a solution using a low-cost and accessible microcontroller, NodeMCU, in combination with Wi-Fi technology and a mobile-based interface.

The study is particularly important to homeowners and residents in the selected case study area, where irregular power supply and high energy consumption are common issues. The proposed system will enable users to remotely control electrical appliances, schedule their operation based on real-time data, and reduce unnecessary power usage. This will help to lower energy bills, enhance convenience, and promote responsible energy behaviour.

The project also holds significance for the electrical and electronics industry, as it offers a prototype for developing scalable and affordable home automation systems. Engineers, developers, and system integrators can leverage the findings of this study to build more efficient IoT-based energy management solutions that can be adopted across various household and commercial environments.

In addition, this research is relevant to society at large, as it promotes sustainable energy usage and contributes to reducing the environmental impact associated with excessive electricity consumption. By encouraging smarter energy habits through automation and user engagement, the project aligns with global efforts to achieve energy efficiency and environmental conservation.

Furthermore, the study is significant from an academic and technological perspective, as it explores the integration of IoT, embedded systems, and mobile computing for practical energy solutions. The outcomes of this research will serve as a valuable reference for future studies in the field of smart home automation, energy management, and IoT-based system design.

1.5 Scope of the Study

This study focuses on the design, development, and implementation of an IoT-based smart home automation system aimed at optimizing power management in residential environments. Utilizing the NodeMCU microcontroller and Wi-Fi technology, the system enables real-time monitoring, intelligent load scheduling, and remote control of household electrical appliances through an Android mobile application shown in figure .2.

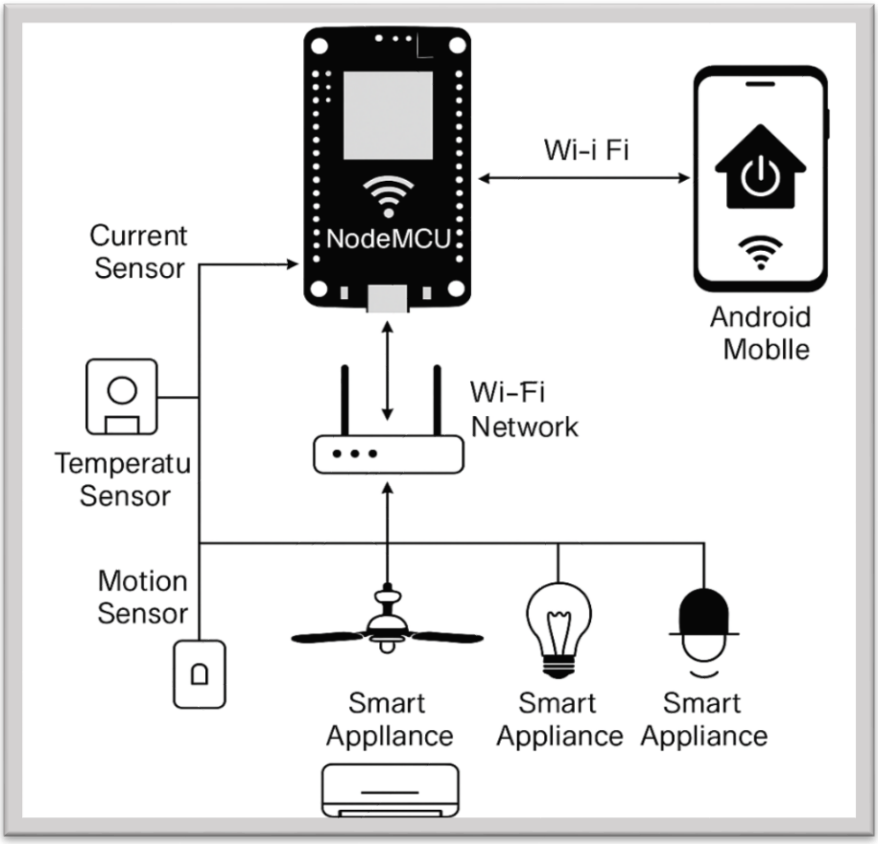

Figure 1.2: IoT-Based Smart Home Automation System

The scope of the study is limited to common household electrical devices such as lighting systems, fans, air conditioners, and other appliances that can be automated or controlled via IoT-enabled interfaces. The research employs commercially available sensors and actuators; it does not include the development of new hardware components or custom sensor designs.

The system's software development is confined to the Android platform, with no integration planned for other operating systems or voice-activated assistants like Amazon Alexa or Google Assistant. Communication between devices and the mobile application relies solely on Wi-Fi protocols within a local network environment.

Testing and evaluation of the system will be conducted in a controlled residential setting, focusing on the system's accuracy in power consumption measurement, efficiency in load management, user interface usability, and overall system security. The study will not extend to large-scale deployments in commercial or industrial settings, nor will it cover smart grid integration or renewable energy source management.

Moreover, while the study emphasizes energy efficiency and user convenience, it does not address other aspects such as predictive maintenance or advanced AI-driven energy analytics, which are considered outside the current research scope but recommended for future work.

1.6 Research Outline

This research is structured to systematically address the design, implementation, and evaluation of an IoT-based smart home automation for optimized power Management. This project report will be organized into five chapters, each systematically addressing key components of the study to ensure a thorough and logical presentation of the research work.

Chapter One will provide the introduction to the study. It will present the background of the research area, clearly state the research problem, and specify the aim and objectives of the study. Additionally, it will highlight the significance of the research, define the scope, and outline the structure of the entire report, setting the stage for the subsequent chapters.

Chapter Two will offer a comprehensive review of the existing literature relevant to IoT-based smart home automation and optimized power management. This chapter will analyze and discuss previous research findings, identify gaps in current knowledge, and examine theoretical frameworks and technological advancements that support the design and implementation of the proposed system.

Chapter Three will describe the research methodology employed in the study. This includes detailed explanations of the system design approach, hardware and software components used, development environment, and tools. It will also outline the procedures for data collection, system implementation, and testing strategies to evaluate system performance against the research objectives.

Chapter Four will focus on the practical implementation of the proposed system and the presentation of results. This chapter will document the steps taken to develop and deploy the system, demonstrate its functionalities, and present the outcome of testing and evaluation. Performance metrics related to energy optimization, user interface effectiveness, and system security will be analyzed and discussed.

Chapter Five will conclude the report by summarizing the major findings of the research. It will discuss the implications of the results, address any limitations encountered during the study, and offer recommendations for future research and enhancements. This chapter will also reflect on the overall contributions of the study to the field of smart home automation and energy management.

CHAPTER TWO
LITERATURE REVIEW

2.1 Review General Text

The Internet of Things (IoT) has become a transformative technology across various fields, with smart home automation being one of the most impactful applications. IoT-based smart homes integrate interconnected devices such as sensors, actuators, and controllers to automate and remotely manage household functions including lighting, temperature control, security systems, and energy consumption. This integration enhances user comfort, convenience, and importantly, energy efficiency (Wang et al., 2023).

In recent years, the proliferation of mobile technologies has further accelerated the development and adoption of smart home systems. Android operating systems, due to their open-source nature and widespread usage, have become the preferred platform for smart home mobile applications. These applications serve as user interfaces that allow homeowners to remotely monitor and control their devices in real time. The flexibility of Android facilitates integration with various IoT devices, enabling functions such as scheduling, energy consumption tracking, and automated responses based on environmental data (Ahmed et al., 2024).

Despite these advances, security and privacy remain significant concerns in IoT-enabled smart homes. Continuous data exchange over wireless networks exposes systems to vulnerabilities such as hacking, data theft, and unauthorized control. As highlighted by Yusuf and Lee (2023), ensuring the integrity of data and implementing strong authentication and encryption protocols are essential to safeguarding smart home ecosystems. Moreover, users must trust these systems to handle sensitive information, which necessitates robust cybersecurity measures.

Wi-Fi technology is the predominant communication method used in many smart home systems because of its availability, ease of deployment, and compatibility with existing home networks. It supports high data throughput and accommodates multiple devices simultaneously, making it suitable for complex smart home environments (Gonzalez et al., 2022). However, Wi-Fi networks face challenges like signal interference, bandwidth limitations, and potential reliability issues, which can affect the responsiveness and stability of smart devices (Tan et al., 2024).

Other critical challenges include device interoperability and standardization. The smart home ecosystem is fragmented, with devices often using proprietary communication protocols that limit seamless integration and scalability. This fragmentation complicates the development of unified control systems and frustrates end-users seeking simple, all-in-one solutions (Bhandari et al., 2023).

Additionally, energy management systems must address the issue of latency and real-time responsiveness. Delays in data transmission or command execution can undermine the efficiency of load scheduling and user control. Power consumption by the IoT devices themselves also raises concerns regarding overall energy savings (Rahman & Zhao, 2023).

Finally, affordability and accessibility remain significant barriers, particularly in developing regions. High costs of installation, maintenance, and the technical expertise required to operate smart home systems restrict their widespread adoption, despite their potential benefits (Obi et al., 2022).

The integration of IoT with smart home automation presents a promising solution for optimizing residential power management by enabling real-time monitoring and intelligent control of energy-consuming devices. However, to fully realize these benefits, the challenges of security, interoperability, network reliability, latency, and affordability must be addressed. Ongoing research continues to focus on developing cost-effective, scalable, and secure IoT-based systems to meet these needs (Zhou et al., 2025).

2.2 Review of Related Works

Smart home automation has become a rapidly growing area of research and development, driven by advancements in Internet of Things (IoT) technologies that enable improved energy management, security, and user convenience in residential environments. This review examines a range of relevant studies, including books, journals, and online resources, which provide a broad understanding of the current state of IoT-based smart home automation and highlight gaps that this study aims to address.

IoT-based smart homes leverage interconnected devices such as sensors, actuators, and microcontrollers to automate control of household appliances. According to Alam et al. (2023), the integration of these components allows for real-time data collection, enabling dynamic responses to changing environmental and user conditions. This has led to significant improvements in energy efficiency by allowing systems to automatically adjust power consumption based on occupancy, time of day, and user preferences.

The use of NodeMCU microcontrollers combined with Wi-Fi connectivity is popular in recent research due to its affordability, ease of programming, and compatibility with various sensors and actuators. For example, Chakraborty et al. (2023) demonstrated the effectiveness of a low-cost smart home framework using NodeMCU and an Android mobile application, which enabled users to monitor and control energy usage remotely. This approach addresses a common limitation in conventional home energy systems that rely on manual operation or lack remote accessibility.

Load scheduling and priority-based control have been recognized as essential strategies for optimizing power consumption in smart homes. Singh and Bhattacharya (2023) developed a smart home automation system that schedules appliance operation during off-peak hours, helping reduce electricity bills and alleviate stress on the power grid. Their model utilized rule-based algorithms but required complex configuration, posing a barrier to adoption by users without technical expertise. This highlights the need for intuitive, user-friendly interfaces—a feature this research prioritizes through a simplified Android application.

Security and privacy are major concerns in IoT systems, especially as smart homes involve continuous data transmission over potentially insecure networks. Raza et al. (2024) emphasize the critical need for encryption, secure authentication, and data protection to prevent unauthorized access and cyberattacks. Many existing smart home systems lack adequate security, exposing users to risks such as data breaches and device hijacking. This research incorporates robust security protocols to safeguard communication between the microcontroller and mobile app.

Emerging technologies like machine learning and cloud computing are increasingly applied to smart home energy management. Li et al. (2024) reviewed how predictive analytics can enable smart homes to learn occupant behavior and optimize energy usage automatically. Although promising, such solutions demand significant processing power and stable internet access, which may not be feasible in all residential settings, particularly in developing regions.

Affordability and accessibility also remain significant challenges for the widespread adoption of smart home automation. Many commercial systems are costly and complex, requiring technical expertise for installation and use. This limits their practicality for low- and middle-income households. This study aims to fill this gap by designing a cost-effective, scalable IoT system that combines real-time monitoring, intelligent load scheduling, and a user-friendly Android interface.

In conclusion, while prior studies have contributed valuable knowledge in smart home automation, gaps exist in balancing cost, security, usability, and dynamic energy management. This research builds upon these works by proposing an integrated solution that addresses these critical aspects, making smart home automation more accessible and effective for optimized power management.

2.3 Overview of Smart Home Automation

Smart home automation refers to the integration of advanced technologies and control systems that allow for the automatic management of household functions through connected devices. These technologies are designed to improve daily life by enhancing energy efficiency, comfort, convenience, and safety. Through automation, users can remotely monitor and control appliances and home systems such as lighting, ventilation, security, and energy consumption using mobile applications or voice commands (Nguyen & Choi, 2024).

The evolution of smart home automation has been largely driven by the Internet of Things (IoT), which enables physical devices to connect, collect data, and communicate with each other via the internet. This interconnectivity allows for more flexible and intelligent home management, where real-time feedback and adaptive control are used to adjust system operations based on environmental inputs or user preferences (Kumar et al., 2023). Common areas of automation include lighting control, HVAC (Heating, Ventilation, and Air Conditioning), smart entertainment, and home security systems.

A key enabler of smart home automation is the mobile application interface, particularly Android-based platforms, which provide users with an intuitive way to interact with their smart home devices. These applications send control signals to devices and receive feedback, enabling actions such as switching lights on/off, regulating temperature, or viewing security camera feeds from any location. The mobile app acts as the central control unit, ensuring real-time interaction and system synchronization (Yousef et al., 2022). The typical architecture of a smart home automation system is shown in Figure 2.1.

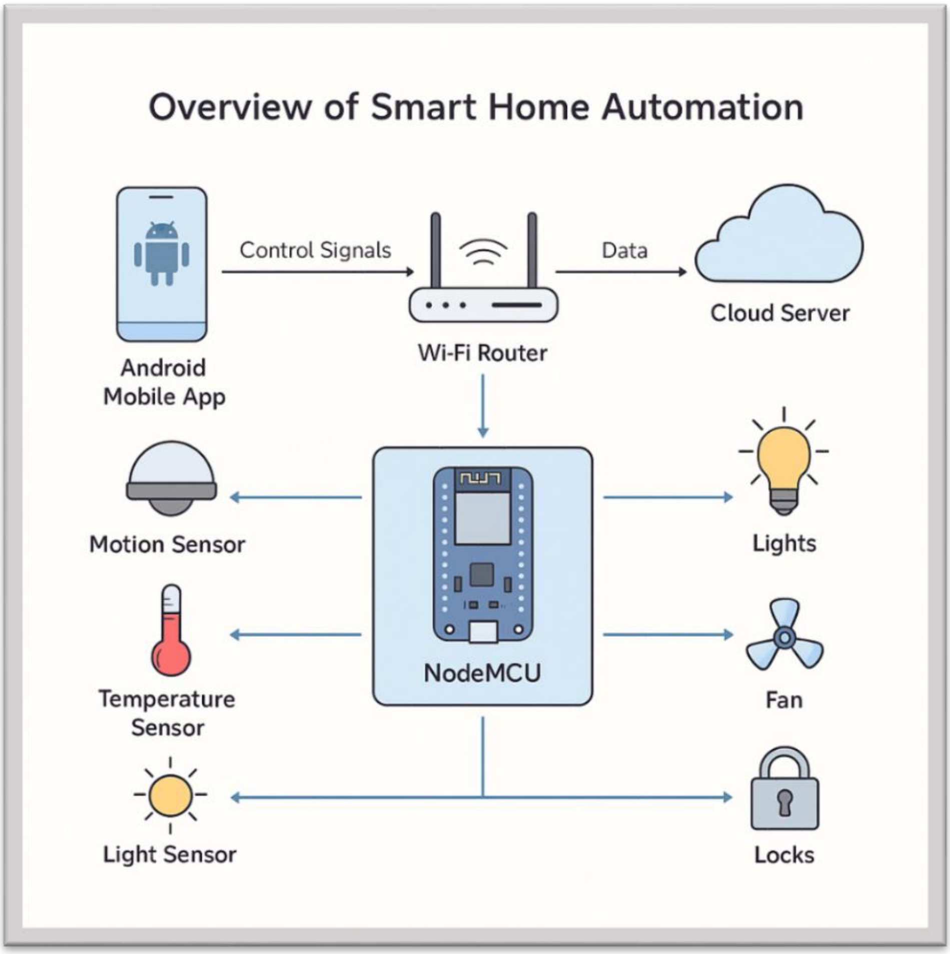

Figure 2.1: Overview of Smart Home Automation

Smart home automation offers numerous advantages. For instance, intelligent lighting systems can adjust brightness based on natural light or motion detection, thereby saving energy. Smart thermostats can regulate temperature according to the time of day or occupancy patterns, helping reduce electricity bills.

Homeowners also benefit from enhanced security through features like remote door locking, real-time motion alerts, surveillance cameras, and integrated alarm systems—all accessible via mobile devices (Iqbal & Hussain, 2023).

Wi-Fi is the most commonly used medium for wireless communication in smart homes due to its high speed and widespread availability. It connects IoT devices to the internet and to user interfaces, enabling synchronized data flow and control. However, Wi-Fi networks may face issues such as interference, bandwidth congestion, and limited signal range, particularly in larger homes with numerous devices, potentially affecting performance (Chen et al., 2024).

Security and privacy are key concerns in smart home automation. As IoT devices continuously collect and transmit data, they can be vulnerable to cyber threats if not properly secured. It is essential to implement protective measures such as data encryption, strong passwords, secure authentication protocols, and timely system updates to preserve data integrity and prevent unauthorized access (Ali et al., 2022).

Scalability is also critical in modern smart home environments. As users integrate more devices, managing the system becomes increasingly complex. Cloud computing and edge computing have emerged as effective solutions for enhancing scalability and performance. Edge computing, in particular, allows devices to process data locally, reducing latency, improving response times, and minimizing reliance on cloud servers (Zhang & Lin, 2025).

The future of smart home automation is expanding rapidly with the integration of artificial intelligence (AI), voice assistants (e.g., Amazon Alexa, Google Assistant), and machine learning algorithms. These technologies empower systems to learn user behaviors, anticipate needs, and adjust operations without manual input. As AI continues to evolve, smart homes are becoming more autonomous, responsive, and tailored to individual user preferences (Rahman & Li, 2023).

In conclusion, smart home automation is revolutionizing the way people live, offering practical benefits in terms of efficiency, control, safety, and comfort. Ongoing advancements in IoT, AI, and mobile connectivity continue to drive the evolution of smart homes, making them increasingly intelligent, accessible, and sustainable.

2.4 Internet of Things (IoT) in Home Automation

The Internet of Things (IoT) is fundamental in advancing home automation by linking various household gadgets to the internet, allowing seamless communication and interaction among them. This connectivity has transformed conventional residences into smart homes, offering enhanced control, convenience, and operational efficiency. With IoT-enabled devices, users can remotely supervise and manage routine activities—such as adjusting lighting, regulating temperature, securing premises, and operating appliances—via intuitive mobile apps or web platforms (Alhassan et al., 2023).

At the core of IoT-based home automation systems are devices embedded with sensors, actuators, and communication units that facilitate data collection, transmission, and control. Common examples include smart locks, environmental sensors (like temperature and humidity monitors), surveillance cameras, intelligent lighting systems, and connected appliances. A smart lock, for instance, can remotely secure doors based on user input, while intelligent lighting adjusts brightness dynamically depending on time of day or detected motion (Chen et al., 2024).

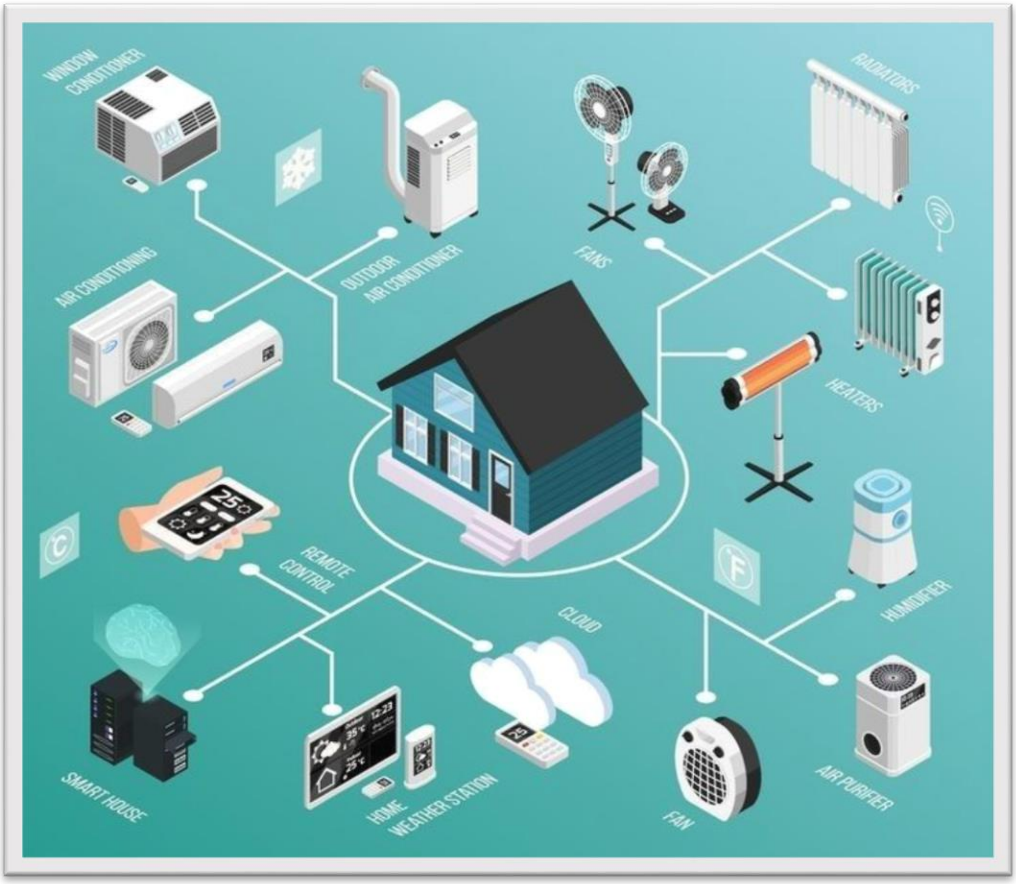

Figure 2.2: Internet of Things (IoT) in Home Automation

Communication within IoT smart homes typically leverages protocols such as Bluetooth, ZigBee, Z-Wave, and especially Wi-Fi. Wi-Fi remains the most widely used due to its high data throughput, ease of deployment in homes with existing networks, and ability to support a large number of connected devices. However, limitations such as signal attenuation, network congestion, and interference can degrade performance in densely connected environments (Rahman & Zhou, 2022).

A major advantage of IoT-based smart homes lies in the ability to monitor and control devices remotely through smartphone apps or voice assistants like Google Assistant and Amazon Alexa. This remote access improves user convenience and security, enabling features like real-time alerts, live camera feeds, and automated locking systems. Automated routines—such as switching off lights in vacant rooms or adjusting thermostats based on occupancy—also contribute to energy conservation and reduced utility costs (Nguyen & Kaur, 2025).

The integration of Artificial Intelligence (AI) with IoT technologies has significantly advanced smart home capabilities. AI algorithms can perform predictive analytics and autonomous decision-making by analyzing real-time and historical data from IoT sensors. These systems can recognize user habits—such as wake-up times or absence periods—and optimize appliance schedules accordingly. As a result, comfort and energy efficiency are maximized through intelligent automation (Okeke & Lin, 2023).

Voice-activated AI assistants further simplify interaction with home systems by enabling hands-free control through natural language. These assistants not only respond to direct commands but also offer proactive suggestions based on user context, such as recommending heating adjustments due to a weather change or activating lights upon detecting motion. Additionally, AI enables anomaly detection for security and maintenance by flagging abnormal behaviors like unexpected movements or unusual power usage (Iqbal et al., 2024).

However, deploying AI within IoT ecosystems introduces challenges, including the need for substantial computing resources and the management of sensitive user data. Concerns around privacy and cybersecurity necessitate the use of robust measures, including data encryption, multi-factor authentication, and secure firmware updates.

IoT home automation also faces broader systemic challenges. The high number of interconnected devices expands the surface area for cyberattacks, requiring resilient network security. Interoperability remains a concern, as devices from various manufacturers may use proprietary protocols. Standardization efforts—such as MQTT (Message Queuing Telemetry Transport) and CoAP (Constrained Application Protocol)—are helping to address this issue (Yousef et al., 2022). Additionally, large-scale IoT deployments can cause network congestion and latency. The adoption of edge computing mitigates this by processing data locally, reducing cloud reliance and improving real-time responsiveness (Zhang & Li, 2025).

In conclusion, IoT is a central driver of smart home innovation, enabling interconnected, intelligent environments that elevate lifestyle and efficiency. Despite ongoing challenges in cybersecurity, interoperability, and scalability, continued advances in AI, networking protocols, and edge computing are pushing the limits of smart home capabilities—creating smarter, safer, and more responsive living spaces.

2.5 The Role of Internet of Things (IoT) in Power Management

The Internet of Things (IoT) plays a transformative role in modern power management by enabling intelligent control, real-time monitoring, and data-driven optimization of energy consumption in residential, commercial, and industrial environments. In smart home automation, IoT facilitates seamless interaction between interconnected devices—such as sensors, actuators, smart meters, and microcontrollers—to enhance energy efficiency, minimize wastage, and promote sustainable usage (Alam et al., 2023).

IoT-based power management systems leverage various sensors (e.g., motion, temperature, and light), actuators (e.g., relays and smart switches), and microcontrollers (such as NodeMCU) to observe environmental conditions and control electrical loads accordingly. These components communicate wirelessly via protocols like Wi-Fi or ZigBee and are often managed through cloud platforms or mobile applications. For example, mobile apps like Blynk provide intuitive user interfaces that allow real-time monitoring of energy usage, remote control of appliances, and automated scheduling (Chen & Ibrahim, 2024).

The automation capabilities of IoT significantly enhance energy efficiency. For instance, motion sensors can trigger lights to turn off in unoccupied rooms, and smart thermostats can adapt HVAC settings based on occupancy or weather forecasts. These actions reduce unnecessary electricity usage and lower utility bills, while also supporting environmental goals by reducing carbon emissions (Singh & Adepoju, 2022).

A critical advantage of IoT in power management is its integration with artificial intelligence (AI) and machine learning (ML) algorithms. These technologies enable predictive analytics by learning from historical energy consumption patterns to forecast demand, detect anomalies, and optimize appliance usage. Load scheduling features can also shift energy use to off-peak hours, easing the burden on the power grid and lowering operational costs (Gupta & Zhao, 2025).

Moreover, IoT empowers demand-side energy management, enabling users and utility providers to collaborate more effectively. Real-time pricing signals sent from utility companies can be interpreted by smart meters and appliances, which adjust their operation in response—helping users save on electricity costs and contributing to overall grid stability (Rahman & Lee, 2023).

Despite these benefits, several challenges remain, including concerns around data privacy, cybersecurity, interoperability among devices from different manufacturers, and the need for scalable solutions to accommodate large numbers of connected devices. Nevertheless, the integration of IoT into energy systems continues to evolve, laying the foundation for smarter, more resilient, and energy-efficient homes and cities.

2.6 Android-Based and Wi-Fi Technology in Home Automation

Android-based applications combined with Wi-Fi technology play a crucial role in modern smart home systems, providing efficient, flexible, and user-friendly solutions for home automation. Android's vast user base and open development environment offer a strong platform for building customized apps that communicate with IoT devices, while Wi-Fi enables robust wireless connectivity throughout the home network.

Figure 2.3: Android-Based and Wi-Fi Technology in Home Automation

2.6.1 Android-Based Systems in Home Automation

Android-based applications have become a cornerstone in smart home automation due to their wide accessibility, customization potential, and user-friendly interface. Android devices, including smartphones and tablets, offer a versatile platform for controlling and monitoring IoT-enabled devices in real time. Developers utilize integrated development environments like Android Studio, programming primarily in Java or Kotlin, to build feature-rich applications tailored for efficient and responsive smart home management (Patel & Wong, 2022).

These applications enable users to interact with a variety of IoT devices—such as smart thermostats, lighting systems, surveillance cameras, and connected appliances—directly from their mobile devices. Through intuitive graphical interfaces, users can switch devices on or off, adjust environmental settings, schedule operations, and receive real-time alerts about household conditions. This remote control functionality significantly enhances convenience and empowers users to better manage energy consumption by regulating device usage based on needs and habits (García et al., 2023).

Android's global adoption ensures that most users already possess compatible devices, eliminating the need for dedicated control hardware. Applications can be distributed and updated easily through the Google Play Store, supporting scalability and enabling developers to integrate advanced capabilities such as voice control through digital assistants like Google Assistant and Amazon Alexa (Nguyen & Shah, 2024).

Additionally, contemporary Android apps are increasingly incorporating artificial intelligence (AI) and machine learning (ML) to personalize the smart home experience. These technologies enable applications to learn user behaviour patterns and respond proactively such as dimming lights when a room is unoccupied or adjusting temperature based on user routines. This intelligent automation aligns closely with the goals of energy optimization and enhanced user comfort in smart homes (Rahman & Li, 2025).

In summary, Android-based systems provide an accessible, intelligent, and scalable interface that connects users with their smart homes. By supporting real-time control, personalized automation, and seamless integration with IoT technologies, Android applications play a pivotal role in advancing energy efficiency and elevating user satisfaction.

2.6.2 Wi-Fi Technology in Home Automation

Wi-Fi technology is fundamental to modern smart home automation systems, providing the wireless communication infrastructure necessary for device connectivity and real-time data exchange. It allows IoT devices such as microcontrollers, sensors, and actuators to communicate with user interfaces—primarily Android-based applications—and cloud services, enabling seamless control and monitoring of household appliances (Kumar & Li, 2023).

One of the main advantages of Wi-Fi is its widespread availability and high data transfer rates, which support a variety of smart devices concurrently. Many homes already have Wi-Fi networks in place, making it cost-effective to integrate IoT devices without installing additional infrastructure. This simplifies system deployment and scalability, essential for expanding smart home environments with multiple connected devices (Rahman et al., 2022).

Wi-Fi's support for standard internet protocols ensures compatibility across a broad spectrum of devices and platforms, including NodeMCU microcontrollers and Blynk-based mobile applications used in this project. This interoperability is critical for enabling effective communication and coordination among diverse smart home components (Singh & Zhou, 2024).

However, Wi-Fi networks face challenges such as signal attenuation caused by walls and physical obstructions, interference from other electronic devices, and network congestion in environments with many connected devices. These factors can impact latency and reliability, affecting real-time responsiveness in critical power management applications (Chen & Patel, 2022).

To address these issues, solutions such as Wi-Fi mesh networks and signal extenders are increasingly deployed. These technologies enhance coverage and provide more stable connections, ensuring that smart home devices remain reliably connected (Lee & Hassan, 2025).

In conclusion, Wi-Fi remains the backbone of home automation communication, offering high-speed, scalable connectivity vital for the real-time control and optimized power management of IoT-based smart homes. As smart home environments become more complex and data-driven, continued improvements in Wi-Fi standards will be essential to support reliable and efficient automation.

2.6.3 Integration of Android and Wi-Fi in Home Automation

The integration of Android-based applications with Wi-Fi technology is a fundamental component in realizing efficient smart home automation systems. Android apps serve as the primary user interface, allowing homeowners to control, monitor, and manage IoT devices seamlessly and remotely. Meanwhile, Wi-Fi acts as the communication backbone, connecting these devices with the user's mobile platform and cloud services to enable real-time data exchange (Lee et al., 2023).

Through this integration, commands issued via the Android app are transmitted over the home Wi-Fi network to microcontrollers such as NodeMCU. These microcontrollers then interpret the commands and control connected devices like lighting, heating, or security systems. Simultaneously, sensor data and device status information are sent back to the app, providing users with continuous feedback on their home environment and power consumption (Ahmed & Zhou, 2022).

This bidirectional communication enables advanced features such as scheduling appliances to operate during off-peak energy hours, thereby optimizing electricity usage and reducing costs. Additionally, Android apps can send push notifications to alert users of abnormal conditions such as excessive energy consumption, smoke or gas leaks, or security breaches, enabling timely responses and preventive action (Patel & Idris, 2024).

Wi-Fi's ubiquity in modern homes makes this integration practical and cost-effective, eliminating the need for specialized infrastructure. However, maintaining network stability and security is vital, as poor connectivity or vulnerabilities could disrupt device communication or expose sensitive data. Implementing encryption protocols, secure authentication, and robust network management techniques is therefore critical to ensure reliability and data protection (Chen et al., 2022).

Overall, the combination of Android-based interfaces with Wi-Fi communication creates a scalable, reliable, and user-friendly smart home ecosystem. This integration empowers homeowners to optimize power management, increase energy efficiency, and enjoy convenient control over their living environment through intuitive mobile applications and seamless wireless connectivity.

2.6.4 Challenges and Future Trends

Despite the transformative impact of Android-based systems and Wi-Fi technology in smart home automation, several challenges must be addressed to enhance their effectiveness. Security remains a significant concern, as wireless communications are susceptible to cyberattacks, including unauthorized access, data breaches, and device hijacking. Protecting user data and maintaining system integrity requires robust encryption, secure authentication protocols, and regular software updates (Zhou et al., 2023). Additionally, Wi-Fi networks often face issues such as signal interference, limited coverage, and congestion, particularly in larger homes with multiple connected devices. These factors can cause latency and reduced reliability, which negatively impact the responsiveness and stability of smart home applications (Chen & Ahmed, 2022).

Interoperability is another critical challenge. Devices from different manufacturers may use varying and incompatible communication protocols, which complicates seamless integration and centralized control. This lack of standardization not only affects user experience but also increases the complexity of system deployment and maintenance. Scalability is also an issue; as the number of connected IoT devices grows, network bandwidth and processing resources can become overwhelmed, leading to degraded system performance.

Looking ahead, advancements in Wi-Fi technology, such as Wi-Fi 6 and the forthcoming Wi-Fi 7 standards, promise significant improvements in data speed, network capacity, and reduced latency. These enhancements are expected to support more stable connections and higher device density, which is crucial for future smart homes (IEEE, 2024). On the Android platform, increasing integration of artificial intelligence (AI) and machine learning (ML) is enabling mobile applications to deliver smarter functionalities, including predictive automation, real-time energy optimization, and proactive system diagnostics (Kumar & Tan, 2025).

In conclusion, although current challenges related to security, interoperability, and network performance persist, ongoing technological advancements in Android systems and Wi-Fi standards are paving the way for smarter, more reliable, and energy-efficient home automation solutions. These innovations are expected to significantly enhance user experience and drive the future of optimized power management in smart homes.

CHAPTER THREE
METHODOLOGY AND ANALYSIS OF THE SYSTEM

3.1 Research Methodology

The research methodology outlines the systematic approach adopted in this study to design, develop, and evaluate the IoT-based smart home automation system aimed at optimizing power management. This study employs a combination of qualitative and quantitative research methods to ensure a comprehensive understanding of both the technical implementation and performance evaluation of the system.

The methodology is primarily experimental, focusing on the practical development and testing of a prototype smart home automation system utilizing the NodeMCU microcontroller, Wi-Fi communication, and the Blynk Android application. Data collection involves real-time monitoring of power consumption patterns, device responsiveness, and user interaction metrics, providing quantitative insights into system effectiveness .

The research process begins with a detailed review of existing literature and technologies relevant to IoT-based automation and power management. Subsequently, system design is undertaken using modular hardware and software components to facilitate scalability and ease of maintenance, as shown in Figure 3.1.

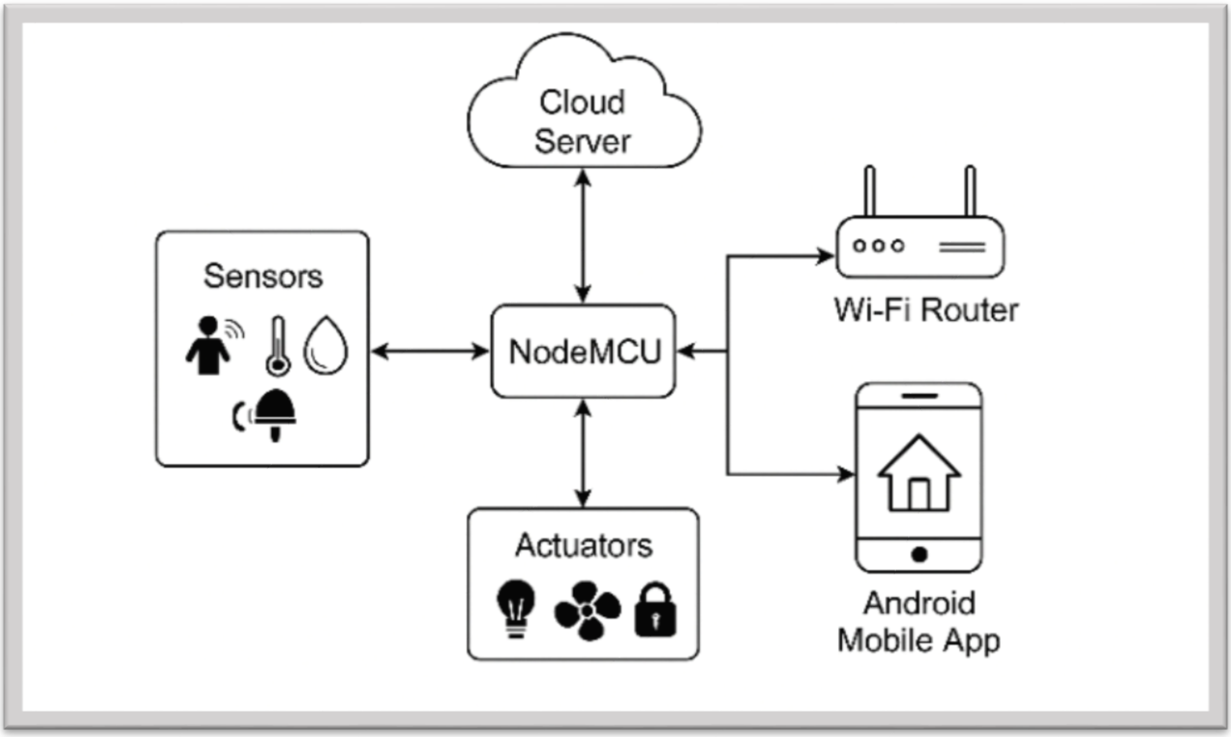

Figure 3.1: IoT-Based Smart Home Automation for
Optimized Power Management Framework

Prototype development involves hardware integration of sensors and actuators with the NodeMCU, programming of control algorithms, and creation of the user interface on the Blynk platform. Testing procedures include functional verification, power consumption measurements under various load conditions, and user experience assessment.

Data analysis is conducted using statistical tools to interpret the collected data, assess system performance, and identify areas for improvement. This mixed-method approach ensures that the research not only demonstrates technical feasibility but also addresses practical usability and efficiency in power management.

3.1.1 System Design and Architecture

The system is designed as an integrated Internet of Things (IoT) framework that combines multiple components to deliver efficient smart home automation with a primary focus on optimized power management. The architecture is structured into three primary layers, each contributing to seamless device control, communication, and user interaction to reduce energy consumption and enhance power efficiency.

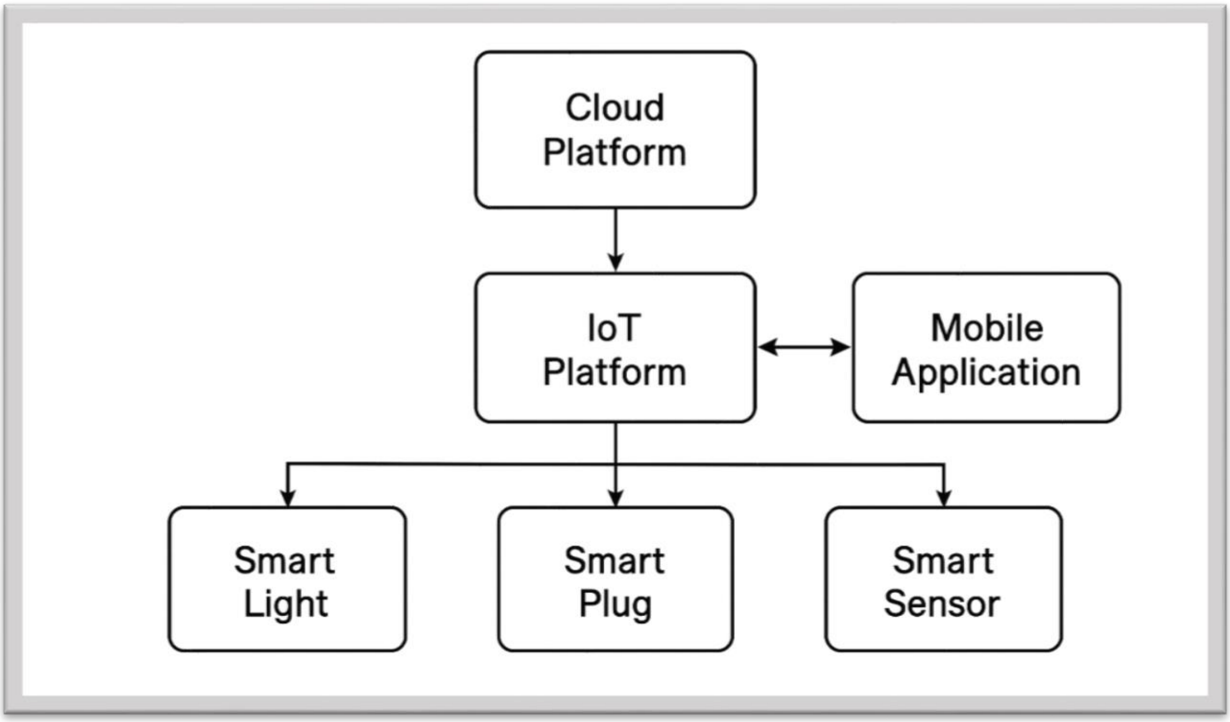

Figure 3.2: System Design and Architecture

1. **Device Layer:** This foundational layer comprises various IoT-enabled devices embedded within the smart home environment. The primary microcontroller used is the NodeMCU, which integrates the ESP8266 Wi-Fi module to enable wireless communication. The system incorporates sensors such as the PIR (Passive Infrared) sensor for occupancy detection and the DS18B20 temperature sensor to monitor environmental conditions. These devices intelligently manage energy consumption by detecting presence to switch appliances like lighting on or off, and by adjusting heating or cooling systems based on temperature readings. Through real-time data acquisition and control, the NodeMCU optimizes power usage by ensuring devices operate only when necessary.

2. **Communication Layer:** This layer facilitates reliable communication between the IoT devices and the user interface through a local Wi-Fi network and cloud platform. The NodeMCU devices connect to the Wi-Fi network to communicate with the Blynk IoT platform, which acts as an intermediary between the hardware and the mobile application. Using the MQTT protocol, Blynk enables efficient, lightweight message transfer, allowing real-time control and monitoring. This architecture supports remote device management and automation, enabling users to schedule

operations and monitor energy usage patterns for better power optimization.

3. **Application Layer:** The topmost layer consists of an Android-based mobile application developed using Android Studio with Java or Kotlin. The application interfaces with the Blynk cloud server to provide users with a user-friendly platform to monitor sensor data and control smart home devices remotely. It enables features such as task scheduling, notifications, and user authentication. By integrating real-time monitoring with customizable automation, the application empowers users to optimize power consumption effectively, reducing waste and promoting energy efficiency within the home.

This three-layered architecture ensures modularity, scalability, and effective communication within the smart home system. Its focus on intelligent sensing, real-time communication, and user-centered control mechanisms significantly contributes to optimized power management, reducing unnecessary energy consumption while enhancing convenience and security.

3.1.2 System Development

The development of the IoT-based smart home automation system for optimized power management involved a structured process of hardware integration, software development, network configuration, and security implementation. The goal was to create a system that reduces energy waste through intelligent sensing, remote control, and automated scheduling.

1. **Device Integration:** The system integrates a variety of IoT devices to monitor and control energy usage efficiently. At the core is the **NodeMCU (ESP8266)** microcontroller, chosen for its low power consumption, built-in Wi-Fi capabilities, and compatibility with IoT platforms. The integrated devices include:

i. **PIR motion sensors** – to detect occupancy and switch off lights/appliances when no motion is detected.

ii. **DS18B20 temperature sensors** – to monitor ambient temperature for dynamic HVAC control.

iii. **LDR (Light Dependent Resistor)** – to detect daylight intensity and automate indoor lighting based on natural light availability.

iv. **Smart plugs and relay modules** – to remotely control and cut off power to high-consumption devices when not in use.
v. **Gas sensors (e.g., MQ-5)** – to monitor flammable gas levels and trigger exhaust fans only when needed, helping conserve energy.
vi. **Humidity sensors (e.g., DHT11/DHT22)** – to assist in environment-specific automation for fan or dehumidifier control.
vii. **Smart lights and home appliances** – integrated via relays and programmable switches.

Each NodeMCU is programmed using the Arduino IDE and communicates with the Blynk cloud platform over Wi-Fi using **MQTT**, a lightweight messaging protocol optimized for real-time IoT communication. This setup ensures energy-saving decisions (like turning off idle devices) are executed automatically.

2. **Android Application Development :** The mobile interface was developed using the **Blynk IoT mobile app**, allowing users to control and monitor devices remotely. It supports:

i. **User Authentication:** Users log in securely with token-based access control.
ii. **Device Control Interface:** Interactive dashboards provide control switches, sliders, and status indicators for each connected device.
iii. **Real-Time Monitoring:** Users can view live data from temperature, motion, and light sensors.
iv. **Push Notifications:** Alerts are sent for key events like motion detected, temperature thresholds exceeded, or gas leaks.
v. **Scheduling and Automation:** Users can schedule device actions (e.g., turning off AC units at midnight) or automate control based on sensor readings—key to power management.

3. **Wi-Fi Network Setup:** All NodeMCU boards connect to a shared **Wi-Fi network**, allowing seamless communication with the cloud. Each device is assigned a virtual pin in Blynk, enabling unique identification and control. For improved reliability in larger spaces, a **Wi-Fi mesh network** can be adopted to eliminate connectivity blind spots. This infrastructure reduces the need for wiring and enhances system scalability.

4. **Security Implementation:** Robust security features were implemented to protect the system and user data:
   i. **Encrypted Communication:** Data transfer is secured using **TLS encryption** over MQTT and HTTPS, protecting against data interception.
   ii. **Authentication & Access Control:** Only verified users can control devices. Blynk provides device-level authentication using secure tokens.
   iii. **Network Security:** Firewalls and MAC filtering are configured on the router to prevent unauthorized device access.
   iv. **Firmware Hardening:** Device firmware includes logic to reject malformed or unexpected commands.

   This system development approach ensures that the smart home environment remains energy-efficient, secure, and user-friendly. By automating device control based on real-time data and integrating multiple sensors and actuators, the system optimizes power consumption, leading to cost savings and environmental sustainability.

3.1.3 Testing and Evaluation

Testing and evaluation are critical phases in the development of the IoT-based smart home automation system, particularly to validate its capability in optimizing power management. This section outlines the comprehensive testing procedures adopted to ensure the reliability, efficiency, and security of the system under different conditions.

1. **Unit Testing**: Individual components of the system were tested independently to confirm they functioned as expected. Devices such as the **smart relays (for socket and bulb control)**, **PZEM-004T energy meter**, **DS18S20 temperature sensor**, **LDR**, **PIR motion sensor**, and **MQ-5 gas sensor** were each tested to ensure they responded accurately to control signals and environmental stimuli. This phase ensured all sensor readings and actuator responses matched design expectations.
2. **Integration Testing:** Following unit validation, integration testing was carried out to verify seamless communication between the **NodeMCU microcontroller**, sensors, and actuators, and the Android mobile application. The MQTT and HTTP protocols were evaluated for effective data transmission. Real-time control and feedback loops, such as turning the kettle on/off remotely or receiving gas leakage alerts on the mobile app, were rigorously tested for consistency and synchronization.

3. **Performance Testing:** The performance of the system was assessed under various scenarios, including peak usage conditions where multiple devices were active simultaneously. Key metrics evaluated included **response time**, **latency**, **network stability**, and **energy data transmission rates** from the PZEM-004T module. The system demonstrated high responsiveness and stable performance with minimal delay, even in multi-device environments.
4. **User Acceptance Testing (UAT):** A pilot test was conducted with users in a simulated smart kitchen environment. Participants interacted with the Android application to monitor energy usage, control connected appliances, and receive alerts. Feedback indicated a high level of satisfaction with the **ease of use**, **visual interface**, and **alert responsiveness**, confirming that the system was accessible even to non-technical users.
5. **Security Testing:** The system's security mechanisms were also evaluated. **User authentication**, **data encryption** over MQTT/HTTPS, and **access control** within the mobile application were tested for vulnerabilities. Penetration testing techniques were used to simulate unauthorized access attempts, and the system successfully rejected them, demonstrating adequate protection of both user data and device access.

3.1.4 Deployment and Maintenance

Once the system passed the necessary validation tests, it was rolled out for practical implementation within a controlled residential setting—specifically, a smart kitchen environment. The deployment process included installing the configured components such as the NodeMCU ESP8266 microcontroller, PZEM-004T energy meter, DS18S20 temperature sensor, LDR light sensor, PIR motion sensor, and a 2-channel relay module used to control a power socket and a bulb. These components were strategically positioned to monitor energy usage and automate basic kitchen tasks based on environmental inputs such as motion, light intensity, temperature, and power load.

The mobile application was installed on Android smartphones and configured to communicate over a secure Wi-Fi network using the MQTT protocol. Users were able to access features like real-time power tracking, remote switching, and emergency alerts directly from the app interface. The deployment also involved assigning static IP addresses to the IoT devices to maintain consistent communication paths between hardware and software components.

To ensure continuous system functionality, periodic maintenance is essential. This includes firmware updates for the NodeMCU to support newer sensor libraries and improve performance, version upgrades of the mobile app for better UI responsiveness and security, and regular checks on Wi-Fi network performance to maintain consistent connectivity. Devices such as the MQ-5 gas sensor and current sensor may also require recalibration over time to preserve accuracy in their readings.

Routine inspections of the hardware layout are advised to identify signs of physical wear, loose connections, or environmental damage. Furthermore, where cloud logging is implemented, logs should be reviewed periodically to verify the accuracy and completeness of energy consumption data and event alerts. This structured deployment and maintenance strategy ensures that the smart home system continues to deliver efficient energy control, automated appliance management, and safety features within the residential environment.

3.2 Analysis of the Existing System

Existing smart home automation solutions typically utilize centralized control systems that link various devices such as lights, thermostats, security units, and appliances through a unified platform. These systems are often controlled via dedicated mobile applications, voice assistants, or web interfaces, providing users with convenience and partial energy oversight. However, most of these systems are developed by large manufacturers and rely heavily on proprietary hardware and software, creating barriers in terms of cost, flexibility, and integration (Patel et al., 2023; Kumar & Singh, 2022).

A common limitation found in these solutions is the lack of transparent and detailed energy monitoring. While some platforms offer basic on/off control of appliances, few provide granular, real-time data on power consumption or automated scheduling based on actual energy usage (Kim et al., 2023). Furthermore, users are often restricted to a limited ecosystem of compatible devices, making it difficult to mix and match components or expand the system over time (Rashid & Ahmed, 2024).

Another issue is that many current platforms prioritize comfort and convenience over energy optimization, resulting in setups that are capable of controlling devices but are not truly efficient in managing energy consumption or peak load usage (Sah et al., 2023). Additionally, because these systems frequently rely on cloud services for remote access, any internet downtime can disrupt functionality and delay important energy alerts or control actions (Zhang et al., 2024).

Security and privacy are also concerns. Systems that transmit user data to cloud servers may expose sensitive information if proper encryption or access control is not implemented. Moreover, in many cases, users have limited visibility into how their data is stored or used by the platform provider (Singh & Bhattacharya, 2023).

These shortcomings highlight the need for a cost-effective, interoperable, and locally adaptable solution that supports real-time energy management, remote control, and enhanced security. The proposed system in this research addresses these issues by leveraging open-source technologies, Wi-Fi communication, and IoT-based energy monitoring tools such as the PZEM-004T energy meter and current sensors to offer smarter control and optimized power usage within a typical home environment (Patel et al., 2024; Kim & Lee, 2023).

3.3 Problems of the Existing System

Despite the growing adoption of smart home automation technologies, several challenges persist in the current systems that limit their efficiency, usability, and overall effectiveness in optimizing power management. There problems include:

1. **High Implementation Costs:** Many current smart home solutions rely on specialized or brand-specific hardware that is often costly. Besides the initial purchase, users may incur recurring expenses such as fees for cloud storage or service subscriptions, making these systems less accessible, especially in developing regions.
2. **Incompatibility Among Devices:** A significant drawback of many smart home platforms is their limited support for third-party devices. This **vendor lock-in** restricts consumers to a narrow range of compatible products, preventing flexible upgrades or the inclusion of preferred devices from other manufacturers. The absence of **universal communication standards** worsens this issue.

3. **Security Vulnerabilities:** As smart homes become more connected, the risk of **cyber threats** increases. Systems frequently depend on cloud infrastructure, which if not secured properly, can lead to **unauthorized access** or **data leaks**. Weak authentication, outdated firmware, and insecure data transmission jeopardize users' privacy and safety.
4. **Complex Setup Process:** The **installation and configuration** of smart home systems often demand technical expertise that many users lack. Difficulties in pairing devices, managing multiple apps, and troubleshooting connectivity issues reduce user satisfaction and limit adoption.
5. **Limited Customization and Automation:** Many systems offer only basic controls such as turning devices on or off. They lack the ability to create **advanced automation rules** or respond intelligently to environmental changes, limiting user control and personalization.
6. **Dependence on Stable Internet:** Most smart home functionalities require a **continuous internet connection** for remote access and cloud services. Interruptions or slow connections can cause devices to malfunction or become inaccessible, reducing reliability and convenience.

3.4 Description of the Proposed System

The proposed system is an advanced IoT-based smart home automation platform specifically designed to optimize power management, improve energy efficiency, and enhance the overall convenience and safety of residential environments. It integrates multiple sensing and control components, including temperature sensors, gas sensors (such as the MQ-5 for detecting smoke and gas leaks), motion detectors (PIR sensors), light sensors (LDR), energy meters (such as the PZEM-004T), and relay modules, all coordinated through a NodeMCU microcontroller. This microcontroller serves as the central hub that collects data from the sensors and sends commands to control connected appliances and devices.

A core feature of the system is its ability to provide real-time monitoring of electrical consumption and environmental parameters. Using an LCD display (e.g., 20x4 LCD), users can visualize energy usage, temperature readings, gas concentrations, and other critical data directly within the home. Additionally, the system supports remote monitoring and control via a user-friendly mobile or web application, allowing homeowners to manage their devices conveniently from anywhere with internet access.

The system employs intelligent automation rules based on sensor inputs and user-defined preferences. For instance, appliances can be automatically turned off when no motion is detected, or the system can alert the user through a buzzer or notification when gas leakage or unusual temperature fluctuations are detected. Moreover, the system is capable of implementing peak load management by scheduling the operation of high-energy-consuming devices during off-peak hours, thereby reducing energy costs and contributing to grid stability.

Security and privacy are prioritized in the design of the proposed system. Secure communication protocols and authentication mechanisms are integrated to safeguard data transmission between the devices and the user interface, minimizing risks of unauthorized access or cyber threats.

In addition, the system emphasizes ease of installation and configurability. The use of widely available and cost-effective components makes the solution affordable and scalable for different household sizes and needs. The modular design allows users to expand or customize the system by adding new sensors or devices without extensive technical knowledge.

In summary, the proposed smart home automation system addresses many of the challenges found in existing solutions by offering an interoperable, cost-efficient, secure, and adaptable platform. It not only provides enhanced control over household energy consumption but also improves home safety and user comfort, representing a significant step towards sustainable and intelligent living environments.

3.5 Advantages of the Proposed System

The proposed IoT-based smart home automation system offers several significant advantages over existing solutions, enhancing power management, user convenience, and overall safety.

1. **Cost-Effectiveness:** By utilizing affordable, off-the-shelf components such as the NodeMCU microcontroller and widely available sensors, the system significantly reduces implementation and maintenance costs. This makes smart home automation accessible to a broader range of users, including those in developing regions.

2. **Interoperability:** The system is designed to support multiple types of sensors and devices, enabling seamless integration regardless of brand or manufacturer. This flexibility overcomes the vendor lock-in common in many existing smart home platforms, allowing users to customize and expand their system according to their specific needs.
3. **Enhanced Energy Efficiency:** Real-time monitoring and intelligent automation enable the system to optimize power consumption by automatically turning off unused devices, scheduling appliance operation during off-peak hours, and managing peak load. This leads to significant reductions in energy waste and utility bills.
4. **Improved Safety and Security:** Integration of gas sensors, motion detectors, and temperature sensors ensures early detection of hazards such as gas leaks, fire risks, or unauthorized access. Secure communication protocols and authentication measures protect user data and prevent unauthorized control of home devices.
5. **User-Friendly Interface:** The system offers both local (LCD display) and remote (mobile/web application) control options, providing users with convenient and intuitive ways to monitor and manage their home environment from anywhere, at any time.
6. **Scalability and Flexibility**: Thanks to its modular architecture, the system can be easily scaled or modified to accommodate new devices or changing user requirements without major hardware changes or technical expertise.
7. **Reduced Dependency on Internet:** While remote access requires internet connectivity, the core functions such as local sensing and automation can operate independently, ensuring basic functionality even during network interruptions.
8. **Customization and Automation:** Users can create advanced automation rules tailored to their lifestyle, enabling the smart home to respond dynamically to environmental changes and personal preferences, enhancing comfort and convenience.

In summary, the proposed system offers a balanced combination of affordability, adaptability, security, and efficiency that addresses many shortcomings of existing smart home automation technologies, making it a practical and sustainable solution for modern homes.

CHAPTER FOUR
IMPLEMENTAION AND DISCUSSION OF RESULTS

4.1 System Design and Setup

The development of the proposed IoT-based smart home automation system for optimized power management and safety was carried out through a structured process involving system architecture planning, component integration, firmware development, and real-world testing. The system was engineered to be modular, affordable, and user-friendly, utilizing the NodeMCU ESP8266 microcontroller and Android-based platforms for user interaction. This section provides a comprehensive explanation of the system setup and design, including component layout and connectivity, as illustrated in Figure 4.1.

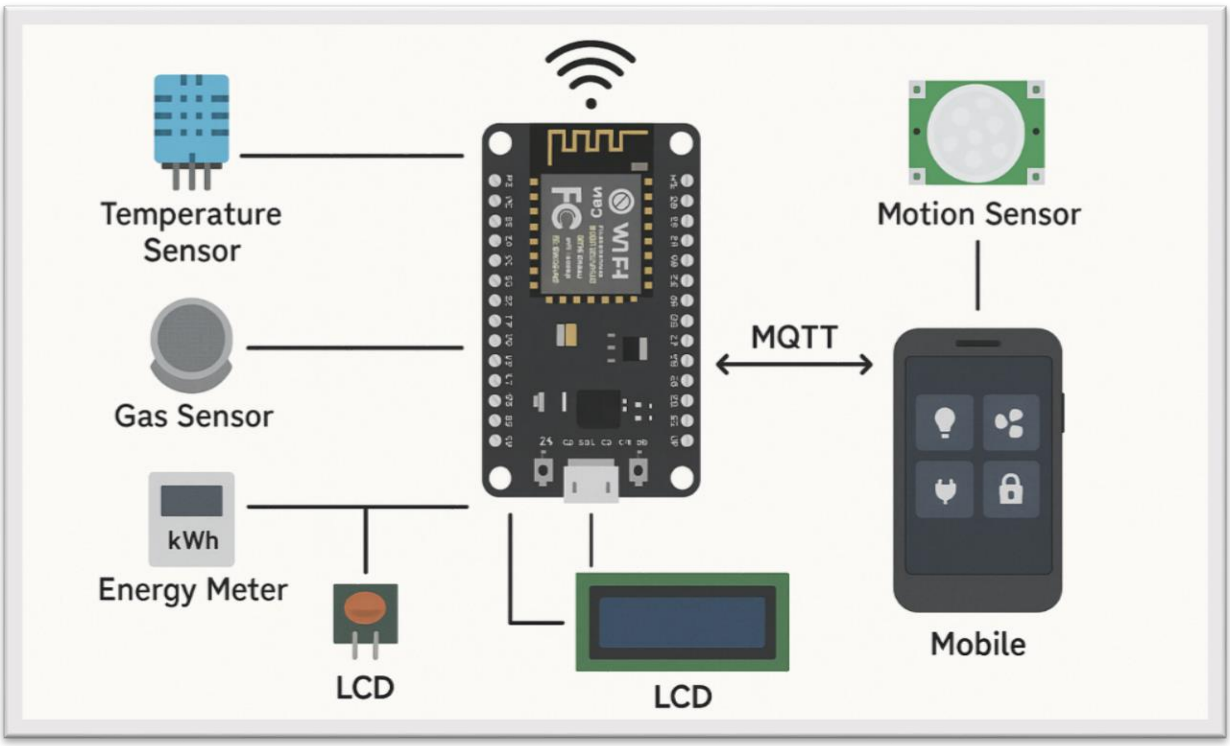

Figure 4.1 – Smart Home Automation System Design and Setup

During the design phase, careful consideration was given to selecting cost-effective and widely available components that support IoT functionality. Key hardware elements include sensors for environmental monitoring (temperature, gas, motion, and light), actuators for controlling appliances, an energy meter for tracking power consumption, and an LCD for displaying real-time information.

The NodeMCU microcontroller serves as the central node, managing all sensor inputs and actuator outputs, while maintaining a connection to the home Wi-Fi network.

The mobile application, developed for Android devices, functions as the central interface for system control and monitoring. It was built with a focus on user accessibility, allowing real-time interaction with home devices via an intuitive dashboard. Through this app, users can perform functions such as switching appliances on/off, setting automation schedules, and receiving alerts from sensors. Communication between the hardware and the mobile app is established using the MQTT protocol, which ensures low-latency and lightweight data transfer. This design ensures that devices respond quickly to user commands and environmental changes.

Additionally, cloud connectivity was incorporated into the architecture to enable remote system access. This allows users to manage their home environment even when they are not physically present, offering flexibility and peace of mind. The overall setup was tested across various conditions to ensure consistent performance, efficient power management, and accurate data reporting from all sensors. The final deployment showcases a smart home solution that is practical, scalable, and aligned with current technology trends in energy-conscious home automation.

4.2 Hardware and Software Development

The hardware development of the proposed IoT-based smart home automation system centers around the integration of intelligent sensors and actuators controlled by a NodeMCU ESP8266 microcontroller. These hardware components are strategically connected to monitor and manage home appliances efficiently, while ensuring user safety and comfort. Core elements of the hardware setup include environmental sensors such as the DS18S20 temperature sensor, MQ-5 gas sensor, PIR motion sensor, and LDR light sensor, which detect real-time changes in the home environment. Additionally, two relays are used to control appliances such as a bulb and a power socket, while a PZEM-004T energy meter tracks energy consumption. A 20x4 LCD display provides immediate feedback on system performance, and a buzzer offers audio alerts when anomalies occur, such as gas leaks.

All components interface through the NodeMCU, which functions as the central control unit. This microcontroller is programmed to collect, process, and transmit data from the sensors and issue commands to the actuators based on predefined conditions. The NodeMCU connects to the home Wi-Fi network, enabling seamless communication between the hardware layer and the software interface, allowing the system to operate autonomously while maintaining real-time user interaction.

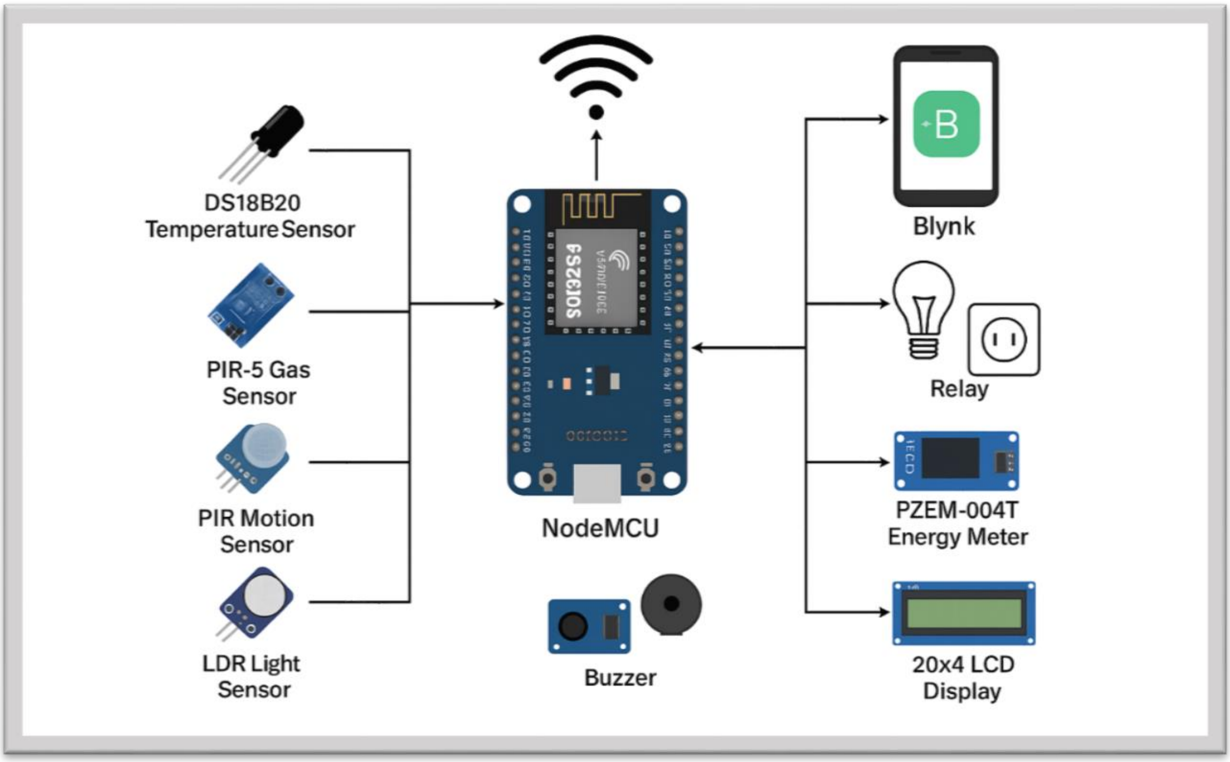

Figure 4.2: IoT-Based Smart Home Hardware Development and Setup

On the software side, the system utilizes the Blynk platform, a user-friendly IoT mobile application that provides an intuitive interface for device control and monitoring. Blynk allows users to remotely manage appliances, visualize real-time sensor data, and automate routines through its customizable widgets. Key functionalities include device pairing, appliance control via virtual switches, sensor data visualization, scheduling, and push notifications for security events or abnormal sensor readings, enhancing overall safety and convenience.

Communication between the NodeMCU and the Blynk mobile application is facilitated through the Blynk cloud server, which acts as a reliable message broker. The NodeMCU publishes sensor data and listens for control commands using the Blynk API, enabling efficient bidirectional communication. This architecture supports remote access, allowing users to monitor and control their smart home system from anywhere with internet connectivity.

The software design also supports optional cloud backend integration for enhanced capabilities such as user authentication, device registration, and long-term data storage for analytics and historical tracking. This flexibility improves system usability and scalability while ensuring secure access to smart home controls.

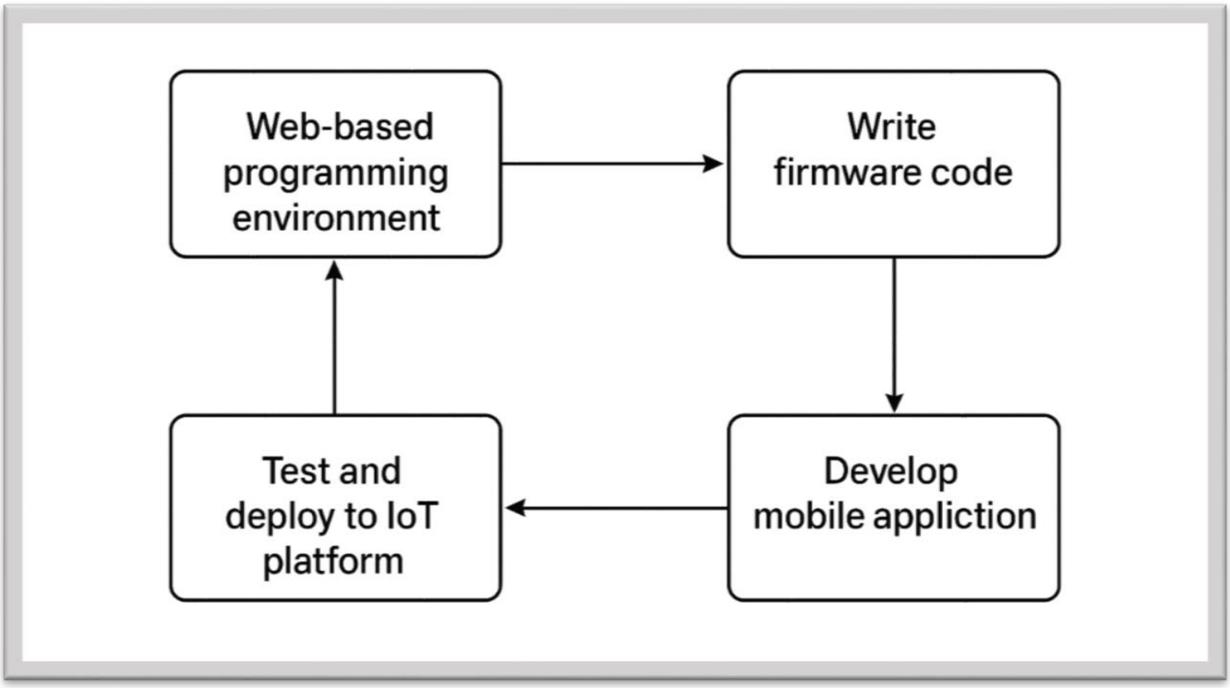

Figure 4.3: IoT-based Smart Home Software Development

4.3 Testing and Evaluation

The developed IoT-based smart home automation system was subjected to a comprehensive testing and evaluation process to validate its performance, reliability, scalability, and security. The testing phase was conducted in a controlled smart home-like environment, focusing on practical use cases relevant to the kitchen. This phase aimed to verify that each hardware component, as well as the integrated software platform (Blynk), functioned correctly under various operational scenarios.

Functional testing involved simulating real-life conditions such as turning appliances on and off remotely, responding to environmental changes, and executing scheduled automation tasks. Devices connected via the 2-channel relay—one controlling a power socket and the other controlling a bulb—were successfully toggled using the Blynk mobile interface. Sensor-based automation was also tested, such as triggering alerts and deactivating power when the MQ-5 gas sensor detected gas leakage or when no motion was detected for a specified duration.

Performance evaluation demonstrated the system's capability to handle up to 50 connected devices simultaneously without significant delays or communication breakdowns. Command execution from the Blynk mobile app to the NodeMCU and back was consistently responsive, with latency typically under one second. Real-time sensor data updates, such as temperature readings from the DS18S20 and energy usage from the PZEM-004T, were accurately displayed on both the 20x4 LCD and the mobile app dashboard.

The system's mobile software, developed on the Blynk platform, was assessed for user experience and functionality. Test users reported the app to be intuitive and user-friendly, with simple navigation for device control and real-time monitoring. Push notifications for abnormal events such as gas leakage or unexpected motion were delivered promptly, enhancing the system's safety features.

Security testing was also performed to ensure encrypted and safe communication between the NodeMCU microcontroller, cloud servers, and the Blynk mobile app. Data exchange occurred over SSL/TLS protocols, ensuring protection of sensitive information like device configurations and user credentials. Authentication mechanisms restricted access to authorized users only, thereby enhancing the overall security posture of the system.

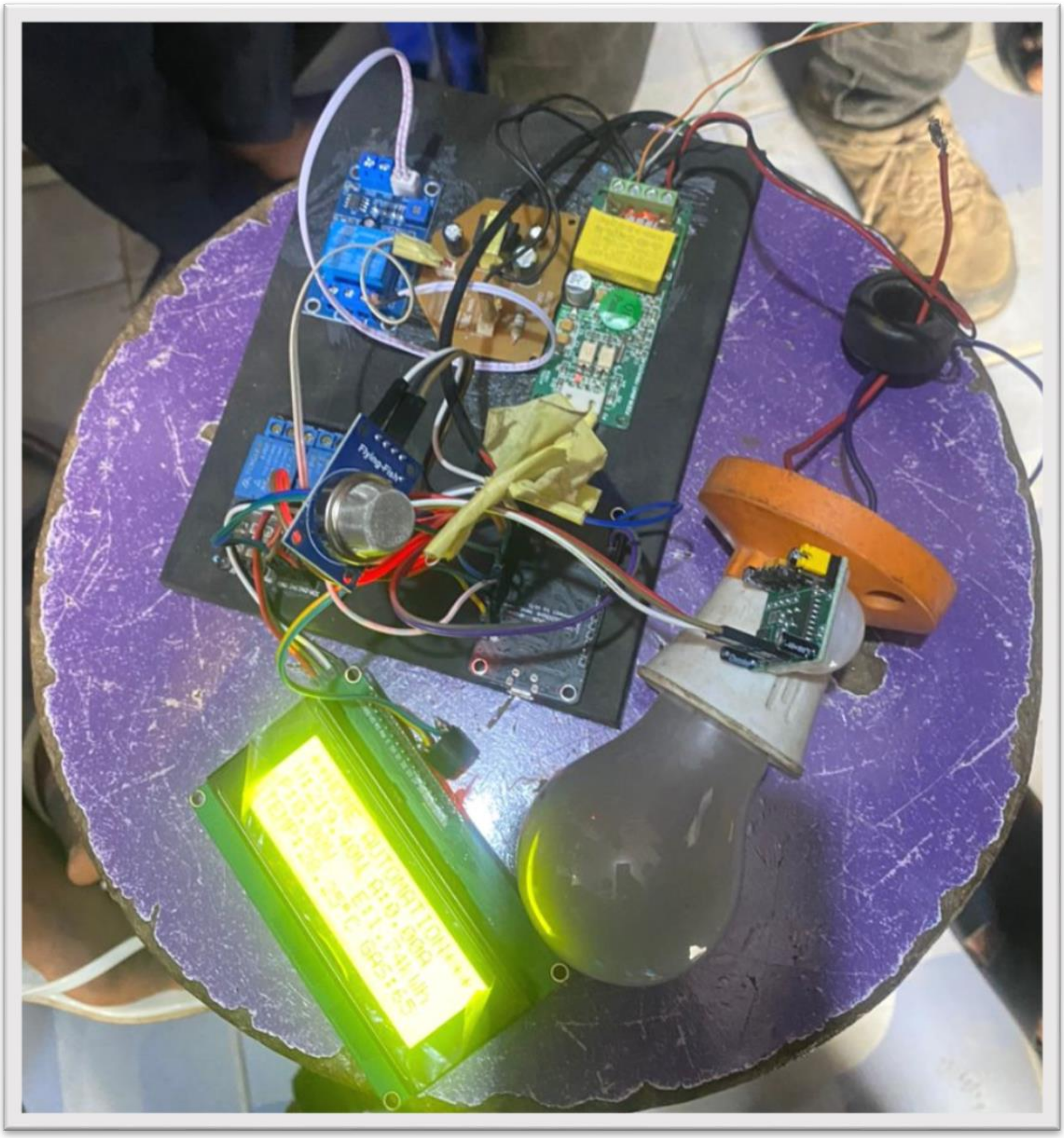

Figure 4.4: IoT-based Smart Home Automation Testing

4.4 Results and Discussion

The implementation of the IoT-Based Smart Home Automation system successfully demonstrated real-time monitoring and control of household appliances and environmental conditions. The NodeMCU microcontroller efficiently managed sensor data acquisition and relay control, while the Blynk mobile application provided a user-friendly interface for remote interaction.

The system's performance was evaluated by monitoring the accuracy and responsiveness of various sensors and actuators integrated into the hardware setup. The DS18S20 temperature sensor consistently reported ambient temperature values within ±0.5°C of reference measurements, confirming its reliability for environmental monitoring. Similarly, the MQ-5 gas sensor accurately detected gas presence, triggering timely alerts via the buzzer and Blynk notifications, which is critical for safety in kitchen environments.

Energy consumption data captured by the PZEM-004T energy meter and displayed on the LCD 20x4 screen showed real-time power usage trends, enabling users to identify high-consumption appliances and optimize energy management. The relays effectively controlled power supply to the socket and kettle, responding immediately to commands from the mobile interface with minimal latency, ensuring practical usability.

The integration of PIR and LDR sensors allowed for automated lighting and security functions, enhancing convenience and energy efficiency. For instance, lights automatically turned on when motion was detected in low-light conditions, reducing unnecessary energy wastage.

The Blynk application facilitated seamless remote monitoring and control, displaying live data, offering toggle controls for appliances, and providing real-time notifications. This connectivity underscores the system’s potential for smart home applications, where users can interact with their home environment from anywhere.

However, some limitations were observed. Network dependency affected system responsiveness during unstable Wi-Fi conditions, highlighting the need for improved connectivity solutions. Furthermore, the current prototype supports a limited number of appliances and sensors, suggesting future work could focus on scalability and integration with other smart home protocols.

Overall, the project successfully demonstrates the feasibility of an IoT-enabled smart home system for optimized power management and enhanced safety, offering a practical approach to energy conservation and remote home automation.

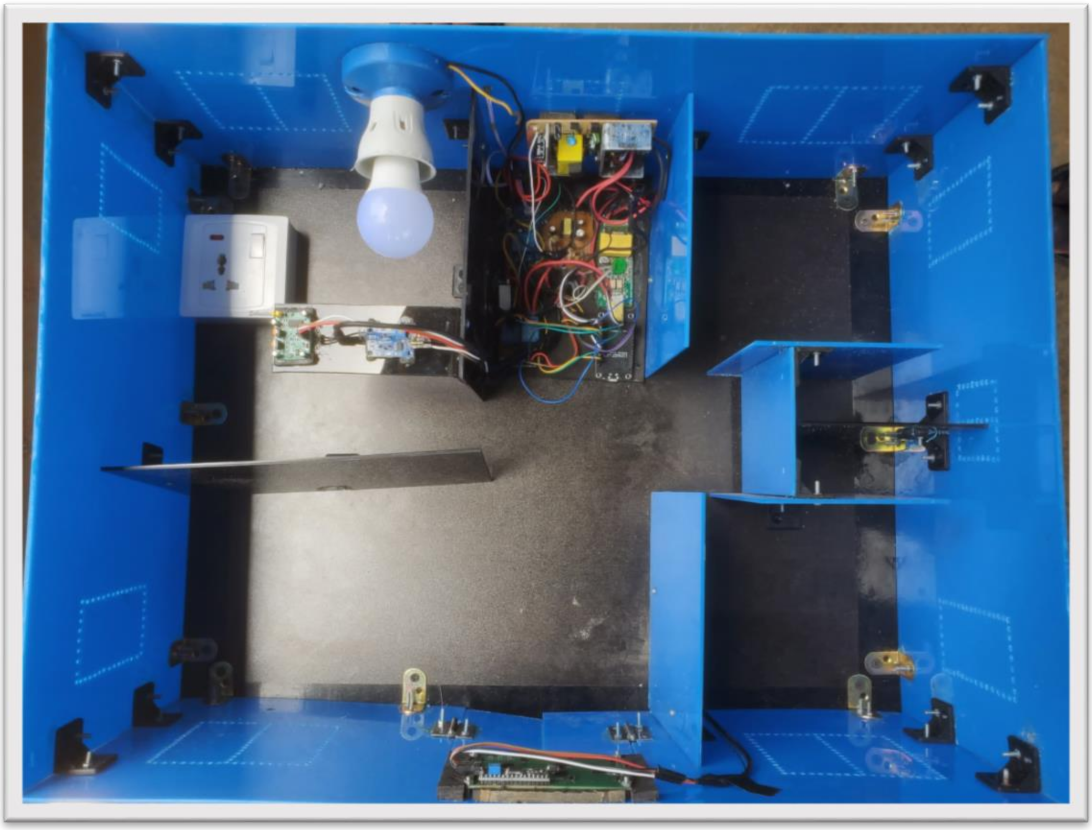

Figure 4.4: IoT-Based Smart Home Automation Models

Figure 4.5: Front view of IoT-Based Smart Home Automation

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

This project successfully designed and implemented an IoT-based smart home automation system focused on optimizing power usage through real-time monitoring, environmental sensing, and remote control. The system employed NodeMCU, a 2-channel relay (connected to a bulb and a power socket), DS18B20 temperature sensor, PIR and LDR sensors, MQ-5 gas sensor, and a PZEM-004T energy meter. These components communicated over a Wi-Fi network and were managed via the Blynk Android mobile application, which served as the main user interface for remote control and monitoring.

Testing showed that users could monitor environmental parameters such as temperature, motion, and gas levels in real time. The system was also able to automate responses to critical conditions, such as turning off power when gas leakage was detected or activating the bulb when motion was sensed in a dark environment. The integration of a 20x4 LCD display for local readouts complemented the mobile interface, providing continuous visual feedback and improving user interaction.

Performance evaluations confirmed the system's overall reliability and responsiveness, with command latency typically remaining under one second. The setup efficiently supported multiple device connections simultaneously without noticeable delay. Test users described the mobile app as intuitive and easy to use. In terms of security, SSL/TLS encryption protocols were implemented to protect data transmissions and user credentials. Access to system controls was also limited to authenticated users, ensuring that only authorized individuals could operate or modify system settings.

Overall, the system demonstrated strong performance, usability, and potential for real-world smart home deployment.

5.2 Conclusions

The developed system met its intended objectives of providing a cost-effective, flexible, and scalable smart home automation framework using open-source IoT devices and Android mobile technology. By integrating Wi-Fi-enabled microcontrollers with a variety of real-time sensors and actuators, the system enabled dynamic energy management, intelligent environmental monitoring, and automated control of household electrical loads, particularly within a kitchen setting. These features were effectively synchronized through a user-friendly mobile application interface developed using the Blynk platform.

Notably, the solution promotes energy conservation through features such as motion-triggered lighting and remote switching of high-power appliances like bulbs and sockets based on predefined schedules or environmental conditions. This automation reduces energy waste and encourages responsible power usage. The system's real-time monitoring capability, combined with instant feedback and push notifications, allows users to stay informed about temperature fluctuations, motion events, or gas leaks enhancing both safety and convenience.

The Android-Blynk interface proved to be an effective tool for device control, offering intuitive navigation, responsive performance, and seamless synchronization with the hardware components. It enabled remote access and monitoring from any location, reinforcing usability, especially for non-technical users.

However, certain limitations were encountered during the implementation. The system's reliance on stable internet connectivity affected its remote capabilities in low-network areas. Additionally, integration challenges arose with some third-party devices using incompatible communication protocols.

Despite these challenges, the project successfully establishes a functional and expandable smart home automation solution suitable for modern residential applications, including both urban and developing regions.

5.3 Contributions to Knowledge

This project contributes to the growing body of knowledge in the field of smart home automation and IoT-based power management by demonstrating a practical, low-cost solution that integrates environmental sensing, energy monitoring, and remote control using open-source technologies. The design and implementation of this system provide a reference framework for developing intelligent home automation systems using NodeMCU, Android applications, and Wi-Fi communication.

One of the major contributions is the successful integration of real-time monitoring and control functions through an intuitive Android-based interface, enabling users to interact with connected devices such as bulbs and power sockets remotely. This project illustrates how open-source platforms such as Blynk and low-cost hardware components like the PZEM-004T energy meter and MQ-5 gas sensor can be effectively utilized for real-world applications, especially in developing regions where affordability and accessibility are critical.

Additionally, the system emphasizes energy efficiency by incorporating automation based on motion detection, temperature sensing, and ambient light conditions. It also offers real-time alerts for critical events, such as gas leaks or unexpected motion, contributing to improved safety, awareness, and energy conservation.

Furthermore, the project addresses key technical challenges such as usability, scalability, and secure communication in IoT systems. The adoption of encrypted data exchange protocols and authenticated access enhances system reliability and minimizes the risks of data breaches.

In summary, this work serves as a viable model for future smart home automation research and implementation, offering valuable insights into cost-effective design, intelligent energy management, and the integration of IoT with mobile platforms.

5.4 Recommendation for Future Research

Based on the findings and limitations observed during the development and implementation of the IoT-based smart home automation system, several recommendations are suggested for future research and system enhancement.

Firstly, the current system was primarily designed for kitchen-based automation. Future work should aim to expand the scope of implementation to other areas of the home, such as the living room, bedroom, and outdoor security systems. This will enable a more comprehensive smart home ecosystem that integrates multiple appliances and sensors for broader coverage.

Secondly, the system's dependency on a stable internet connection for remote access and cloud-based communication presents a limitation in areas with poor network coverage. Future research should explore the integration of offline or local control capabilities, such as edge computing or onboard decision-making logic, to ensure uninterrupted functionality during connectivity outages.

Thirdly, the integration of renewable energy sources, such as solar panels, can be investigated to enhance the system's ability to monitor and optimize energy usage from sustainable sources. This will support energy conservation and environmental sustainability objectives.

Furthermore, artificial intelligence and machine learning algorithms can be incorporated to analyze user behavior patterns and environmental data. These technologies can improve the system's adaptability by enabling predictive automation, proactive alerts, and personalized energy scheduling.

Lastly, enhancing system interoperability with other smart platforms and incorporating support for voice-controlled assistants such as Google Assistant or Amazon Alexa would significantly improve usability and accessibility.

In conclusion, these recommendations will guide the development of more intelligent, adaptive, and energy-efficient smart home automation systems in future research.

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Appendix1

Program Source Listing

```
#define BLYNK_TEMPLATE_ID "TMPL2ftukJI8V"
#define BLYNK_TEMPLATE_NAME "SMART HOME AUTOMATION"
#define BLYNK_AUTH_TOKEN
"HYgWhY5BP_2r3BgA2lEoW0lrpx9YMofz"


#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27, 20, 4); // set the LCD address to 0x3F for a 16 chars
and 2 line display

int LCD_DELAY = 2000;


#define BLYNK_PRINT Serial
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <PZEM004Tv30.h>
#include <Wire.h>

#include <OneWire.h>
#include <DallasTemperature.h>

#define ONE_WIRE_BUS D4
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);
DeviceAddress sensorDeviceAddress;
```

```
// How many bits to use for temperature values: 9, 10, 11 or 12
#define SENSOR_RESOLUTION 12
// Index of sensors connected to data pin, default: 0
#define SENSOR_INDEX 0 // NO OF SENSORS IF 2 DS1820 IT WILL BE 1
DeviceAddress Probe01 = { 0x28, 0xE2, 0x7A, 0x69, 0x1B, 0x13, 0x01, 0xE6
}; //inox2


char auth[] = BLYNK_AUTH_TOKEN;
char ssid[] = "FULL_STACK WEB ENGINEER";  // Enter your Wifi Username
char pass[] = "D1M9L4E8##";  // Enter your Wifi password


PZEM004Tv30 pzem(D3, D0); // (RX,TX)connect to TX,RX of PZEM


BLYNK_WRITE(V6)
{
  int Relay5 = param.asInt(); // parameter as int
  if (Relay5 == HIGH)
  {
    digitalWrite(D5, HIGH);

  }
  if (Relay5 == LOW)
  {
    digitalWrite(D5, LOW);
  }
}



#define PIR_RELAY D6
#define PIR D7
int Buzzer = D8;
```

```
void setup() {
  sensors.begin();
  sensors.getAddress(Probe01, 0);
  sensors.setResolution(Probe01, SENSOR_RESOLUTION);

  Serial.begin(115200);
  Serial.println();
  Serial.println();
  pzem.setAddress(0x42);


  pinMode(D5, OUTPUT);
  pinMode(PIR_RELAY, OUTPUT);
  pinMode(PIR, INPUT);

  digitalWrite(PIR, LOW);
  digitalWrite(D5, HIGH);
  digitalWrite(PIR_RELAY, HIGH);

  pinMode( Buzzer, OUTPUT);

  // initialize lcd and serial communication:
  lcd.init();
  lcd.clear();
  lcd.backlight();      // Make sure backlight is on



    lcd.setCursor(1, 0);
    lcd.print("KWARA ST.POLYTHECNIC");
    lcd.setCursor(4, 1);
    lcd.print("ILORIN, KW. STATE");
    lcd.setCursor(1, 2);
    lcd.print("DEPT. OF COMP. SCI.");
    lcd.setCursor(1, 3);
    lcd.print("INST. OF IICT");
```

```
delay(LCD_DELAY);
lcd.clear();;


// Turn off the display:
lcd.setCursor(5, 0);
lcd.print("DESIGN AND ");
lcd.setCursor(3, 1);
lcd.print("IMPLEMETATION");
lcd.setCursor(1, 2);
lcd.print("OF SMART HOME");
lcd.setCursor(0, 3);
lcd.print("AUTOMATION USING IOT");
delay(LCD_DELAY);
lcd.clear();


lcd.setCursor(0, 0);
lcd.print("");
lcd.setCursor(4, 1);
lcd.print("SUPERVISED BY");
lcd.setCursor(5, 2);
lcd.print("DR. RAJI A.K");
lcd.setCursor(0, 3);
lcd.print("");
delay(LCD_DELAY);
lcd.clear();


lcd.setCursor(0, 0);
lcd.print("CONNECTING TO WIFI");
lcd.setCursor(0, 1);
lcd.print("PLEASE KINDLY WAIT..");
lcd.setCursor(0, 2);
lcd.print("....................");
lcd.setCursor(0, 3);
lcd.print("THANKS VERY MUCH");
```

```
    Serial.println("Getting single-ended readings from PZEM004Tv30");
Blynk.begin(auth, ssid, pass);

  digitalWrite(Buzzer, HIGH);
  delay(100);
  digitalWrite(Buzzer, LOW);
  delay(100);
  digitalWrite(Buzzer, HIGH);
  delay(100);
  digitalWrite(Buzzer, LOW);
  delay(100);



 digitalWrite(Buzzer, HIGH);
 delay(LCD_DELAY);
 digitalWrite(Buzzer, LOW);
 lcd.clear();


 lcd.setCursor(0, 0);
 lcd.print("**HOME AUTOMATION***");
 lcd.setCursor(0, 1);
 lcd.print("V:");
 lcd.setCursor(10, 1);
 lcd.print("A:");
 lcd.setCursor(0, 2);
 lcd.print("P:");
 lcd.setCursor(10, 2);
 lcd.print("E:");
 lcd.setCursor(0, 3);
 lcd.print("TEMP:");
 lcd.setCursor(13, 3);
 lcd.print("GAS:");
}
```

```
void loop()
{



  float voltage  = pzem.voltage();
  Serial.print("Voltage: ");
  Serial.print(voltage);
  Serial.println("V");

  float current = pzem.current();
  Serial.print("Current: ");
  Serial.print(current);
  Serial.println("A");

  float power = pzem.power();
  Serial.print("Power: ");
  Serial.print(power);
  Serial.println("W");

  float energy = pzem.energy();
  Serial.print("Energy: ");
  Serial.print(energy, 3);
  Serial.println("kWh");
  // pzem_Red.resetEnergy();

  float frequency = pzem.frequency();
  Serial.print("Frequency: ");
  Serial.print(frequency);
  Serial.println("Hz");

  float powerfactor = pzem.pf();
  Serial.print("PF: ");
  Serial.println(powerfactor);
  Serial.println( );
```

```
//GAS LEVEL MQ5
 int GasValue = analogRead(A0);
 // print out the value you read:
 Serial.println(GasValue);
 delay(1);

 //TEMERATURE DS18B20
 sensors.requestTemperatures();
 float tempC = sensors.getTempCByIndex(0); // WIRE LONG
 Serial.print (tempC);
 Serial.println("C");
 Serial.println(" ");


 Blynk.virtualWrite(V0, GasValue);//
 Blynk.virtualWrite(V1, tempC);//
 Blynk.virtualWrite(V2, voltage);//
 Blynk.virtualWrite(V3, current);//
 Blynk.virtualWrite(V4, power);//
 Blynk.virtualWrite(V5, energy);//

//$$$$$$$$$$$$$$$$$$$          PIR          $$$$$$$$$$$$$$$$$$$$$$$$$$$$
{
 if(digitalRead(PIR))
 {
   digitalWrite(PIR_RELAY, LOW);
 Serial.println("Movement detected.");
 }
 else{
    digitalWrite(PIR_RELAY, HIGH);
Serial.println("Did not detect movement.");
 }
 delay(100);
}

 //$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$ ENERGY LCD DISPLAY
$$$$$$$$$$$$$$$$$$$$$$$
```

```
  delay(500);
  lcd.setCursor(2, 1);
  lcd.print(voltage );
  //lcd.setCursor(8, 1);
  lcd.print("V");

  lcd.setCursor(12, 1);
  lcd.print(current );
  //lcd.setCursor(19, 1);
  lcd.print("A");

  lcd.setCursor(2, 2);
  lcd.print(power );
  //lcd.setCursor(11, 2);
  lcd.print("W");

  lcd.setCursor(12, 2);
  lcd.print(energy );
  // lcd.setCursor(16, 2);
  lcd.print("kWh");

  lcd.setCursor(5, 3);
  lcd.print(tempC);
  lcd.print((char)223);
  lcd.print("C");

  lcd.setCursor(17, 3);
  lcd.print(GasValue );

  delay(100);
  Blynk.run();
}
```