Development and Evaluation of an IoT-Based Plant Monitoring System.

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DECLARATION

I affirm that the content presented in this thesis is the result of my own research and original work. It does not include any material previously submitted for academic purposes at any other institution, nor does it contain content that has been previously published or authored by another individual, except where proper acknowledgment is provided within the text. I acknowledge my right to utilize this material, either in its entirety or in part, for future academic endeavors such as articles or books.

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I confirm that the student named above conducted research for their PhD/MPhil/Masters thesis/dissertation under my supervision. I verify that the declaration made by the student is accurate and truthful.

Name of Supervisor: Dr. ATP Silva

Signature of the Supervisor: Date: 17.07.2024

DEDICATION

This work is dedicated to my family, whose steadfast love and encouragement have been a constant source of strength throughout my academic journey. I extend my heartfelt gratitude to my supervisors for their invaluable guidance and patience, which have significantly shaped my research efforts. Finally, this thesis is dedicated to all plant enthusiasts and horticulturalists, whose dedication to nurturing plants continually inspires innovation and advancement in plant care practices.

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ABSTRACT

The increasing popularity of indoor and outdoor plant cultivation has led to a growing demand for effective and user-friendly plant care solutions. However, existing methods often rely on manual observation and intervention, resulting in labor-intensive processes and suboptimal plant health outcomes. Concurrently, advancements in Internet of Things (IoT) technology offer promising avenues for revolutionizing plant care practices through real-time monitoring, data analysis, and remote-control capabilities.

In response to these challenges, this research proposes the development and evaluation of an IoT-Enhanced Smart Plant Monitoring System, designed to address the need for comprehensive, user-friendly, and sustainable plant care solutions. The proposed system leverages IoT technology to collect and analyze critical environmental data, including soil moisture, light exposure, temperature, and humidity, from both indoor and outdoor plant environments. Utilizing NODEMCU devices and a centralized processing unit, the system offers real-time plant insights, personalized recommendations, and remote care control functionalities.

Key features of the proposed system include a user-friendly interface for seamless interaction and accessibility, remote control capabilities via IoT cloud platform, and sustainability considerations to minimize environmental impact. Through a comprehensive review of existing literature, methodology development, and real-world testing, this research seeks to evaluate the effectiveness and usability of the IoT-Enhanced Smart Plant Monitoring System in addressing plant care challenges.

Furthermore, implications for future research, industry applications, and societal benefits are discussed, highlighting the potential impact of IoT technology in advancing plant care practices and promoting environmental sustainability. In conclusion, the proposed IoT-Enhanced Smart Plant Monitoring System represents a significant step forward in the realm of plant care technology, offering a holistic and sustainable solution to the challenges faced by plant enthusiasts and horticulturalists. By harnessing the power of IoT technology and data analytics, this innovative system empowers users to make informed decisions, optimize plant health, and foster a deeper connection with nature in both indoor and outdoor settings.

Keywords: Plant care, IoT technology, Smart monitoring system, Remote control.

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CHAPTER 1

INTRODUCTION

1.1 Prolegomena

The Internet of Things (IoT), a transformative force reshaping our interaction with the physical world, has found applications across a wide array of domains. [1]. This research embarks on the development and evaluation of an IoT-Based Smart Plant Monitoring System, building upon the foundation of IoT technology and addressing the contemporary challenge of effective plant care and management. Efficient plant care remains a pressing issue for plant enthusiasts and horticulturalists [2]. Maintaining optimal conditions for plant growth can be complex and labor-intensive, leading to suboptimal outcomes. To mitigate these challenges, this research leverages IoT technology for continuous monitoring of critical environmental parameters, such as soil moisture, light exposure, temperature, and humidity [3]. Proposed solution involves the creation of an integrated IoT ecosystem, comprising an array of sensors, data collection mechanisms, and a user-friendly interface [4]. This system aims to empower plant owners with real-time insights into their plants' conditions, enabling informed decision-making and precise care [5]. Through data analysis and remote-control capabilities, the system seeks to optimize plant health, promote sustainability, and enhance the overall plant-keeping experience [6]. Another study also emphasizes on that point in a deep way [7].

This chapter is organized to present the following: O Aim and Objectives, background and motivation, Problem in brief, proposed solution, resource requirements, structure of the thesis and summary.

1.2 Aim and Objectives

The aim of this research is to conceive, develop, and evaluate an innovative IoT-Enhanced Smart Plant Monitoring System tailored to confront the multifaceted challenges inherent in contemporary plant care practices. This system is envisioned to revolutionize conventional plant monitoring methodologies by harnessing the power of IoT technologies, thereby facilitating real-time data acquisition, analysis, and actionable insights. Through meticulous design and rigorous evaluation, this research endeavors to provide a comprehensive solution that not only optimizes plant health but also enhances user experience, sustainability, and overall efficacy in plant care management.

The aim and objectives of this research are as follows:

- Conduct a comprehensive review of existing plant care challenges and IoT-based solutions and identify specific gaps and limitations in current plant monitoring practices.
- Research and evaluate IoT technologies suitable for plant monitoring by selecting appropriate sensors, communication protocols, and hardware components for the system.
- Design and Develop IoT-Enhanced Smart Plant Monitoring System and Implement data analysis algorithms and recommendation engines for optimizing plant care.
- Deploy the developed system for real-world testing and collect data on system performance, user satisfaction, and plant health improvement.
- Evaluate the effectiveness of the system in addressing the identified challenges.

1.3 Background and Motivation

In recent years, the Internet of Things (IoT) has transformed industries and lifestyles by enabling smart, data-driven solutions. In the context of plant care, IoT technology offers a promising avenue to optimize conditions for plant growth and health [8]. Traditional plant care methods often fall short in achieving these goals efficiently. Several achievements in IoT-enabled plant monitoring have been made, with the development of systems that track critical environmental factors like soil moisture, light, temperature, and humidity in real-time [3]. However, challenges remain, such as the need for comprehensive, user-friendly systems for both indoor and outdoor plants, as well as ensuring long-term sustainability and energy efficiency [9].

However, despite significant strides, several unsolved issues persist in this area. Existing solutions often lack comprehensiveness and may not cater to both indoor and outdoor environments. Moreover, they may not offer user-friendly interfaces or the ability to remotely control and optimize plant care based on collected data [4]. Additionally, ensuring the long-term sustainability and energy efficiency of IoT plant monitoring systems remains an ongoing challenge [5].

The motivation to address these issues stems from the overarching goal of harnessing IoT technology to streamline and enhance plant care practices. Among these challenges, the primary focus of this research is to develop an IoT-Based Smart Plant Monitoring System that addresses current limitations, providing effective solutions for both indoor and outdoor plant environments. [9]. The chosen technology, IoT, presents a challenging but promising avenue for delivering a comprehensive, user-friendly, and sustainable solution to the persistent problems in plant care. The ability to address these challenges is underpinned by collective expertise in IoT technology, data analytics, and system design [10]. It will drive by the vision of empowering plant enthusiasts and horticulturalists with an accessible, data-driven toolset that optimizes plant care, promotes sustainability, and enhances the overall plant-keeping experience [11]. In doing so, we aim to contribute to the broader field of IoT applications while making a tangible impact on the everyday lives of plant owners and the health of our natural environment.

1.4 Problem in Brief

The lack of a comprehensive, user-friendly, and sustainable IoT-based solution for monitoring and optimizing plant health in both indoor and outdoor environments poses a significant challenge. Existing plant care methods are often labor-intensive and limited in providing real-time insights, while many IoT-based solutions lack versatility and ease of use. Addressing this gap requires the development of an innovative Smart Plant Monitoring System that leverages IoT technology to provide actionable insights and personalized recommendations for plant care, promoting sustainability and enhancing the overall plant-keeping experience.

1.5 Proposed Solution

The solution to the identified challenges lies in the creation and deployment of an IoT-Enhanced Smart Plant Monitoring System. This cutting-edge system is thoughtfully engineered to meet the varied requirements of plant care enthusiasts, both indoors and outdoors. Utilizing the capabilities of IoT technology, data analytics, and intuitive user interfaces, the Smart Plant Monitoring System provides real-time insights and allows for remote management of plant care, transforming the methods used to monitor and enhance plant health.

At the core of the system lies the utilization of NODEMCU devices, strategically positioned to collect pertinent data from each plant or nursery. These NODEMCU units' interface with a range of sensors to gather crucial environmental data, including soil moisture, light exposure, temperature, and humidity. Subsequently, this data is transmitted wirelessly using Wi-Fi connectivity to a central processing unit. Here, advanced algorithms analyze the data against a comprehensive plant database and user-defined preferences.

Based on the analysis, the system generates actionable recommendations tailored to the specific needs of each plant. These recommendations encompass a wide range of interventions, from adjusting watering schedules to optimizing lighting conditions, all aimed at enhancing plant health and vitality. Furthermore, the system's intuitive user interface provides plant enthusiasts and horticulturalists with seamless access to real-time plant data, recommendations, and alerts, empowering them to make informed decisions and take proactive measures to ensure optimal plant care.

One standout feature of the Smart Plant Monitoring System is its extensive monitoring capabilities, which go beyond fundamental environmental parameters to encompass holistic indicators of plant health. Moreover, the system includes a user-friendly interface designed for easy navigation and interaction, ensuring accessibility for users of all skill levels. Moreover, its remote-control functionality enables users to remotely manage and monitor their plants from anywhere, at any time, via the IoT cloud platform.

The technological processes underpinning the Smart Plant Monitoring System include data collection, data analysis, recommendation engine algorithms, and user interface design. These processes work in tandem to provide a seamless and integrated user experience, facilitating informed decision-making and proactive plant care practices. Users of the system, including plant enthusiasts and horticulturalists, stand to benefit from its comprehensive monitoring capabilities, user-friendly interface, remote control functionality, data-driven recommendations, alerts and notifications, and commitment to sustainability.

In summary, the IoT-Enhanced Smart Plant Monitoring System marks a significant advancement in plant care, providing a comprehensive and sustainable solution to challenges encountered by plant enthusiasts and horticulturalists alike.By leveraging cutting-edge IoT technology and data analytics, this innovative system empowers users to optimize plant health, promote sustainability, and enhance the overall plant-keeping experience.

1.6 Resource Requirements

Computer Hardware: Personal computers/laptops, IoT hardware components, Mobile devices

Software: IDE for microcontroller programming, Data analysis tools, Simulation software, Documentation and writing software

Internet Access: Reliable internet access

Laboratory Hours: Access to laboratory facilities

IoT Hardware Components: Soil moisture sensors, light sensors, microcontrollers, communication modules

Data Storage and Backup: Adequate storage and backup solutions

Technical Support: Access to technical support.

1.7 Structure of the Theses

This thesis structured into 8 chapters. Those are Introduction, Developments and challenges in the IOT-Based Smart Plant monitoring system, Technology adapted, An Approach to IOT-Based Smart Plant monitoring system, Design, Implementation, Evaluation and Conclusion and Further Work.

1.8 Summary

In this introduction chapter, the research sets out to address the pressing need for a comprehensive, user-friendly, and sustainable solution for monitoring and optimizing plant health in both indoor and outdoor environments. Acknowledging the constraints of current plant care methodologies and IoT solutions, this research proposes the creation and deployment of an innovative IoT-Enhanced Smart Plant Monitoring System. By thoroughly investigating plant care challenges and the evolution of IoT technology, this study seeks to address these gaps by providing timely plant data insights, remote management capabilities, and data-driven suggestions to plant enthusiasts and horticulturalists. The chapter provides an overview of the proposed solution's key aspects, including its technological processes, user interface design, and sustainability features, setting the stage for a comprehensive exploration of the research objectives, methodology, findings, and implications in subsequent chapters. In Chapter 2, We'll discuss about the Developments and challenges in the IOT-Based Smart Plant Monitoring System in detail.

CHAPTER 2

DEVELOPMENTS AND CHALLENGES IN THE IOT-BASED SMART PLANT MONITORING SYSTEM

2.1 Introduction

In chapter 1, we have provided the overall picture of the theses. This chapter gives the comprehensive literature review in the area of IOT technology. This chapter has been structured to covering following sub sections named Gestation of IOT-Based Smart Plant Monitoring System, Major developments in IOT-Based Smart Plant Monitoring Systems, Future directions of the IOT-Based Smart Plant Monitoring Systems, Summary of challenges in the IOT-Based Smart Plant Monitoring Systems, Problem definition and finally the summary of the chapter.

Within the literature, the components and functionalities of IoT-Based Smart Plant Monitoring Systems are elucidated. These systems typically comprise sensor nodes deployed within plant environments, a central processing unit for data aggregation and analysis, and user interfaces for visualization and control. By continuously monitoring and analyzing plant data, these systems provide valuable insights into plant health status, empowering users to make informed decisions and implement proactive measures to optimize plant care. Despite the advancements in IoT-based plant monitoring technology, challenges such as sensor calibration and maintenance, data privacy and security concerns, and the need for user-friendly interfaces persist. Addressing these challenges is crucial to ensuring the widespread adoption and effectiveness of IoT-Based Smart Plant Monitoring Systems in enhancing plant care practices and promoting sustainability in agriculture and horticulture.

2.2 Gestation of IOT-Based Smart Plant Monitoring System

The evolution of IOT-Based Smart Plant Monitoring Systems has been shaped by the contributions of researchers and innovators across various disciplines. Notable among these is the work of Bhatnagar et al. (2020) and Absar et al, who proposed a pioneering approach to plant monitoring using IoT technology [12]. In their studies, they developed a comprehensive system consisting of wireless sensor nodes deployed in plant environments and a central processing unit for data aggregation and analysis. Through real-time monitoring of critical environmental parameters such as soil moisture, light exposure, temperature, and humidity, the system provided valuable insights into plant health status, facilitating informed decision-making for plant care practices [5].

Building upon this foundation, Shibani et al. explored the integration of machine learning algorithms into IOT-Based Smart Plant Monitoring Systems [13]. By leveraging machine learning techniques, their system demonstrated enhanced predictive capabilities, enabling more accurate plant health assessments and proactive intervention strategies. The incorporation of machine learning algorithms allowed for the development of personalized recommendations tailored to the specific needs of each plant, thereby optimizing plant care practices and promoting sustainable agriculture.

In addition to these seminal works by Musa et al., the gestation of IOT-Based Smart Plant Monitoring Systems has been facilitated by advancements in technology. Wireless sensor networks (WSNs) have played a pivotal role in enabling real-time data collection from plant environments [14]. For example, they developed a WSN-based plant monitoring system with capable of monitoring soil moisture levels in agricultural fields with high precision. The deployment of WSNs allowed for comprehensive monitoring of plant health parameters, leading to improved crop yield and resource utilization in agricultural settings.

Moreover, microcontroller platforms such as Arduino and Raspberry Pi have provided researchers with versatile tools for developing IoT-enabled plant monitoring systems [15]. These platforms offer cost-effective and customizable solutions for implementing IOT-Based Smart Plant Monitoring Systems in diverse environments. For instance, Sharma utilized Arduino-based sensor nodes to monitor environmental parameters and optimize plant growth conditions in greenhouse settings [16]. The flexibility and affordability of microcontroller platforms have contributed to the widespread adoption of IoT technology in plant monitoring applications.

Despite the advancements, challenges persist in the development and implementation of IOT-Based Smart Plant Monitoring Systems [17]. Calibrating and maintaining sensors are crucial steps to uphold the accuracy and dependability of collected data [18]. Additionally, concerns regarding data privacy and security in IoT systems remain significant, particularly when transmitting sensitive plant health information over wireless networks [19]. Moreover, challenges with interoperability among diverse IoT devices and platforms can impede smooth integration and data exchange, thereby constraining the scalability and effectiveness of IoT-based Smart Plant Monitoring Systems [20].

The research work by Barnwal et al., presents a detailed exploration of the design and implementation of a smart plant monitoring system leveraging IoT technology and NodeMCU. The authors address the growing demand for effective plant care solutions by proposing an innovative system capable of real-time monitoring, data analysis, and remote-control functionalities [6]. Some other paper presents a valuable contribution to the field of plant monitoring technology. By leveraging IoT technology and NodeMCU, the proposed system offers promising capabilities for enhancing plant care practices and promoting sustainable agriculture [21].

In summary, the gestation of IOT-Based Smart Plant Monitoring Systems has been marked by significant contributions from researchers and advancements in technology. While these systems hold great promise for revolutionizing plant care practices, addressing the associated challenges will be crucial in realizing their full potential.

2.3 Major developments in IOT-Based Smart Plant Monitoring Systems

In recent years, significant advancements have been made in the development of IOT-Based Smart Plant Monitoring Systems, revolutionizing the way plants are cared for and managed. These developments encompass various aspects, including sensor technology, data analytics, and user interfaces, leading to more efficient and effective plant care practices.

One notable development is the integration of advanced sensor technologies into plant monitoring systems. Research by Yin et al., demonstrated the use of high-precision soil moisture sensors capable of providing accurate and real-time measurements of soil moisture levels in plant environments [22]. Similarly, advancements in light exposure sensors, temperature sensors, and humidity sensors have contributed to comprehensive monitoring of environmental parameters essential for plant growth and health.

Another key development lies in the implementation of data analytics algorithms for plant health assessment and optimization. Studies such as the work by Liu et al. explored the application of machine learning techniques for predictive plant health monitoring in IoT environments, enabling personalized recommendations for plant care based on data analysis [23]. By leveraging historical data and predictive modeling, these algorithms facilitate proactive management of plant health issues and optimization of care practices [13].

Furthermore, advancements in user interfaces and remote-control functionalities have enhanced the accessibility and usability of IOT-Based Smart Plant Monitoring Systems. The research conducted by marcue et al. focused on developing user-friendly interfaces for seamless interaction with plant monitoring systems, enabling plant enthusiasts and horticulturalists to access real-time plant insights and control functionalities remotely [24]. Through intuitive interfaces and mobile applications, users can monitor plant health status, receive notifications, and adjust care settings with ease [25].

NodeMCU, a versatile platform based on the ESP8266 Wi-Fi module, has been instrumental in driving innovation in IoT-based plant monitoring projects. Several research initiatives have leveraged NodeMCU for its robust connectivity and compatibility with the Arduino IDE, enabling seamless integration with sensor nodes and data processing units. Projects showcased the use of NodeMCU in developing a cost-effective and scalable plant monitoring system for urban agriculture settings [26]. By deploying NodeMCU-based sensor nodes in conjunction with cloud-based data storage and analysis platforms, the project demonstrated the feasibility of monitoring plant health and environmental conditions remotely. Similarly, utilized NodeMCU for implementing a distributed plant monitoring network, allowing for real-time data collection and analysis across multiple locations [27]. These projects highlight the versatility and adaptability of NodeMCU in addressing the diverse needs of IoT-based plant monitoring applications, paving the way for enhanced sustainability and productivity in agriculture and horticulture sectors.

2.4 Future directions of the IOT-Based Smart Plant Monitoring Systems

As IoT technology continues to advance, the future of plant monitoring systems holds promising opportunities for innovation and progress. Several key areas emerge as potential directions for future research and development, aimed at enhancing the effectiveness, scalability, and sustainability of IoT-based Smart Plant Monitoring Systems. These include:

- **Enhanced Sensor Technology**: Continued development in sensor technology can improve the accuracy, reliability, and durability of sensors used in plant monitoring systems. Innovations such as low-power sensors, multispectral sensors, and sensors capable of detecting additional plant health parameters could expand the capabilities of these systems.
- **Integration of AI and Machine Learning**: Incorporating artificial intelligence (AI) and machine learning (ML) algorithms can enable predictive analytics and personalized plant care recommendations. AI can analyze vast datasets collected from sensors to identify patterns, optimize resource usage, and predict plant health outcomes more accurately.
- **Edge Computing**: Implementing edge computing capabilities can reduce latency and bandwidth usage by processing data closer to where it is generated (at the edge of the network). This can improve real-time responsiveness and reduce dependency on cloud infrastructure, especially in remote or bandwidth-constrained environments.
- **Blockchain for Data Security**: Utilizing blockchain technology can enhance data security and integrity within IoT ecosystems. By creating a decentralized and tamper-proof ledger, blockchain can ensure transparent and trustworthy data exchange between devices, users, and stakeholders in plant monitoring systems.
- **Environmental Monitoring and Adaptability**: Future systems could expand beyond basic plant parameters to include comprehensive environmental monitoring. This could involve integrating weather forecasting data, air quality sensors, and other environmental factors to provide more holistic insights into plant health and growth conditions.
- **User-Centric Design**: Improving user interfaces and user experience (UX) design can make plant monitoring systems more accessible and intuitive for users of varying technical expertise. User-centric design principles can simplify navigation, enhance visualization of data, and facilitate seamless interaction with the system.

- **Scalability and Deployment Flexibility**: Designing systems that are easily scalable and adaptable to different environments (e.g., home gardens, commercial greenhouses) can broaden the applicability of IoT-based plant monitoring solutions. This includes considering modular architectures and flexible deployment options.
- **Sustainability and Resource Efficiency**: Promoting sustainability through IoT-based plant monitoring systems involves optimizing resource usage (water, energy) based on real-time data insights. Implementing smart irrigation systems and energy-efficient controls can reduce environmental impact while promoting healthier plant growth.

By focusing on these areas of innovation, future research and development efforts can contribute to advancing IoT-based Smart Plant Monitoring Systems, making them more robust, efficient, and capable of meeting the evolving needs of plant care enthusiasts and horticulturalists.

One potential direction is the integration of advanced sensing technologies for more precise and comprehensive plant monitoring. Emerging sensor technologies, such as hyperspectral imaging and spectroscopy, offer the capability to analyze plant health at a molecular level, providing insights into nutrient deficiencies, disease detection, and stress responses. By incorporating these advanced sensors into IOT-Based Smart Plant Monitoring Systems, researchers can enhance the accuracy and granularity of plant health assessments, enabling proactive management strategies and targeted interventions.

Another promising direction lies in the utilization of artificial intelligence (AI) and machine learning algorithms for predictive analytics and decision support in plant care. By leveraging historical data on environmental conditions, plant growth patterns, and disease outbreaks, AI-powered algorithms can forecast future plant health trends and recommend optimal care strategies. These predictive capabilities empower plant enthusiasts and horticulturalists to anticipate and mitigate potential risks, thereby improving overall plant health outcomes and resource efficiency.

Furthermore, the development of integrated smart farming platforms represents a future direction for IOT-Based Smart Plant Monitoring Systems. By integrating plant monitoring functionalities with other aspects of smart agriculture, such as irrigation management, crop optimization, and pest control, researchers can create holistic solutions for sustainable and efficient crop production. These integrated platforms enable seamless data sharing and interoperability between different agricultural systems, fostering synergy and optimization across the entire farming ecosystem.

In addition, advancements in communication protocols and network infrastructure are essential for scaling IOT-Based Smart Plant Monitoring Systems to larger agricultural landscapes. The deployment of low-power, wide-area networks (LPWANs) and satellite communication technologies enables connectivity in remote and rural areas, facilitating the adoption of IoT solutions in diverse agricultural settings. By expanding the reach and coverage of IoT networks, researchers can extend the benefits of plant monitoring technology to farmers and growers worldwide, thereby contributing to global food security and environmental sustainability.

2.5 Summary of challenges in the IOT-Based Smart Plant Monitoring Systems

Despite the significant advancements in IOT-Based Smart Plant Monitoring Systems, several challenges persist, impeding their widespread adoption and effectiveness in real-world applications. The foremost challenge lies in ensuring sensor accuracy and reliability, as many commercially available sensors may suffer from inaccuracies and calibration issues over time, leading to unreliable data and erroneous plant health assessments. Integrating heterogeneous sensor networks and data sources poses another significant challenge, requiring technical solutions to fuse, synchronize, and standardize disparate data streams for comprehensive plant monitoring.

Furthermore, issues related to data privacy, security, and ownership present significant hurdles in IOT-Based Smart Plant Monitoring Systems. Plant health data collected by IoT sensors may contain sensitive information, raising concerns about privacy and confidentiality. Additionally, the potential for data breaches and cyber-attacks poses risks to the integrity and security of plant monitoring systems, necessitating robust security measures and data encryption protocols.

Moreover, the scalability and cost-effectiveness of IOT-Based Smart Plant Monitoring Systems remain key challenges, particularly for small-scale and resource-constrained users. Deploying and maintaining sensor networks across large agricultural landscapes or indoor environments can be prohibitively expensive and complex, limiting accessibility and affordability. Finding cost-effective solutions and scalable deployment strategies is essential for democratizing access to plant monitoring technology and promoting its widespread adoption.

Addressing these challenges requires interdisciplinary efforts and innovative solutions to unlock the full potential of IoT technology in revolutionizing plant care practices, promoting sustainability, and enhancing food security worldwide.

2.6 Problem definition

The problem at hand revolves around the inefficiencies and limitations of current plant monitoring practices, particularly in the context of indoor and outdoor environments. Traditional methods rely heavily on manual observation and intervention, leading to labor-intensive processes and suboptimal plant health outcomes. Moreover, existing plant monitoring solutions often lack comprehensiveness, user-friendliness, and sustainability, hindering their effectiveness in addressing the diverse needs of plant enthusiasts and horticulturalists. The challenge lies in developing an IOT-Based Smart Plant Monitoring System that overcomes these shortcomings, offering real-time insights, remote control functionalities, and data-driven recommendations for optimizing plant care practices. By addressing these deficiencies, the proposed system aims to revolutionize plant monitoring technology and promote more efficient and sustainable plant care practices.

2.7 Summary

The chapter delves into the literature of IOT-Based Smart Plant Monitoring Systems by covering around 25 research papers. It highlights persistent challenges such as sensor accuracy, data integration, privacy concerns, scalability, and cost-effectiveness. These challenges hinder the widespread adoption and effectiveness of plant monitoring technology. However, through interdisciplinary efforts and innovative solutions, there's potential to overcome these obstacles and unlock the transformative benefits of IoT in revolutionizing plant care practices. The chapter emphasizes the importance of addressing these challenges to promote more efficient, user-friendly, and sustainable plant monitoring solutions, ultimately contributing to enhanced plant health and environmental sustainability. Chapter 3 presents the in-depth study of IOT technology and its uses of the cultivation.

CHAPTER 3

TECHNOLOGY ADAPTED

3.1 Introduction

In chapter 2 it was clearly discussed about the literature review for this research work. This chapter provides a comprehensive understanding of the technology landscape surrounding IoT-based plant monitoring, highlighting its significance, innovations, and potential impact on plant care practices and agricultural sustainability. By examining key components, principles, and use cases, this chapter elucidates the underlying technologies driving IOT-Based Smart Plant Monitoring Systems and offers insights into their current state, challenges, and future prospects. The following sections will delve into the background and significance of IOT-Based Smart Plant Monitoring Systems, key components and principles, technological advancements, applications and use cases, challenges and limitations, current research, and future directions, culminating in a summary of the chapter's findings.

3.2 Background and Significance of the IOT-Based Smart Plant Monitoring Systems

In recent years, IOT-Based Smart Plant Monitoring Systems have emerged as transformative tools for revolutionizing plant care practices and agricultural management. These systems leverage IoT technology to monitor, analyze, and optimize the growth conditions of plants in both indoor and outdoor environments, offering real-time insights and automated control functionalities. The significance of IOT-Based Smart Plant Monitoring Systems lies in their ability to address longstanding challenges in plant care, such as manual observation, inefficient resource utilization, and suboptimal plant health outcomes. By integrating sensors, data analytics, and remote-control capabilities, these systems empower plant enthusiasts, horticulturalists, and agricultural professionals to monitor and manage plant health more effectively, leading to improved yields, resource efficiency, and environmental sustainability.

The evolution of IoT-Based Smart Plant Monitoring Systems stems from advancements in sensor technology, wireless communication, and data analytics, which collectively enable the real-time collection of vital plant growth data. Modern sensors, now more affordable and energy-efficient, accurately measure environmental parameters like soil moisture, temperature, light exposure, and humidity, providing unprecedented insights into plant health. Improved wireless protocols such as Wi-Fi, Bluetooth, and Zigbee ensure seamless connectivity between sensors, microcontrollers, and cloud platforms, facilitating remote monitoring and control of plant care systems from any location with internet access. These integrated technologies have transformed plant care practices by enhancing precision, scalability, and accessibility in monitoring and optimizing plant growth conditions. Moving forward, further advancements in these fields promise continued innovation and efficiency in global plant care management.

The significance of IOT-Based Smart Plant Monitoring Systems extends beyond individual plant care to broader agricultural and environmental contexts. By enabling precision agriculture, smart irrigation, and environmental monitoring, these systems contribute to sustainable agriculture practices, water conservation efforts, and climate change mitigation strategies. Moreover, IOT-Based Smart Plant Monitoring Systems have the potential to enhance food security, promote urban agriculture, and foster community engagement in plant care initiatives. As such, these systems represent a paradigm shift in plant care practices, offering scalable and accessible solutions for addressing the evolving challenges of modern agriculture and environmental stewardship.

3.3 Key Components and Principles of the IOT-Based Smart Plant Monitoring Systems

IOT-Based Smart Plant Monitoring Systems comprise several key components and operate on fundamental principles to enable effective monitoring, analysis, and management of plant health. Understanding these components and principles is essential for designing and implementing robust and efficient plant monitoring systems.

- **Sensors:** At the core of IOT-Based Smart Plant Monitoring Systems are sensors capable of measuring various environmental parameters critical for plant growth, such as soil moisture, temperature, rain detection, light intensity, , motion detector, humidity, and pH levels. These sensors come in various forms, including soil moisture sensors, temperature and humidity sensors (DHT11 sensor), light sensors, rain sensor, PIR sensor, and pH sensors. Sensors gather real-time data on plant conditions, which serves as the foundation for subsequent analysis and decision-making.
- **Microcontrollers:** Microcontrollers serve as the control center of IOT-Based Smart Plant Monitoring Systems, facilitating data acquisition, processing, and communication with external devices and platforms. Commonly used microcontrollers include Arduino boards, Raspberry Pi, and ESP8266-based modules like NodeMCU. Microcontrollers receive data from sensors, execute programmed algorithms for data processing and analysis, and transmit processed data to cloud platforms or user interfaces for visualization and action.
- **Communication Protocols:** IOT-Based Smart Plant Monitoring Systems rely on communication protocols to facilitate seamless data exchange between sensors, microcontrollers, and external devices. Wireless protocols such as Wi-Fi, Bluetooth, Zigbee, and LoRaWAN are commonly used for local and remote

communication, enabling real-time monitoring and control of plant conditions from anywhere with internet connectivity.

- **Cloud Platforms:** Cloud platforms play a crucial role in IOT-Based Smart Plant Monitoring Systems by providing centralized data storage, processing, and visualization capabilities. Platforms such as AWS IoT, Google Cloud IoT, and Microsoft Azure IoT enable scalable and secure storage of sensor data, analytics for deriving insights from data, and user-friendly interfaces for visualizing plant health metrics and receiving alerts and notifications.
- **User Interfaces:** User interfaces serve as the gateway for users to interact with IOT-Based Smart Plant Monitoring Systems, enabling them to visualize plant health data, set preferences, and receive notifications. User interfaces can take various forms, including mobile applications, web-based dashboards, and dedicated hardware displays. These interfaces provide intuitive and customizable tools for users to monitor plant conditions, adjust settings, and take informed actions to optimize plant health.

By leveraging these key components and principles, IOT-Based Smart Plant Monitoring Systems offer a comprehensive and integrated approach to plant care, enabling precise monitoring, analysis, and management of plant health in diverse environments.

3.4 Technological Advancements and Innovations of IOT-Based Smart Plant Monitoring Systems

In recent years, IOT-Based Smart Plant Monitoring Systems have undergone significant technological advancements and innovations, driving their evolution from simple sensor networks to sophisticated, data-driven platforms for optimizing plant health. These advancements encompass various aspects of hardware, software, and data analytics, enabling more accurate, efficient, and user-friendly plant monitoring solutions.

- **Miniaturization and Integration of Sensors:** One of the notable advancements in IOT-Based Smart Plant Monitoring Systems is the miniaturization and integration of sensors, allowing for the development of compact and multi-functional sensor modules. Manufacturers have produced sensors that combine multiple sensing capabilities, such as soil moisture, temperature, and light intensity, into a single integrated package. This miniaturization and integration enhance system scalability, reduce hardware complexity, and improve overall system reliability and performance.
- **Edge Computing and Local Data Processing:** Another significant innovation is the adoption of edge computing and local data processing capabilities within IOT-Based Smart Plant Monitoring Systems. Edge computing refers to the processing and analysis of data at or near the source of data generation, such as microcontrollers or gateway devices. By performing data processing tasks locally, edge computing reduces reliance on cloud infrastructure, minimizes

latency, and enhances system responsiveness. Moreover, local data processing enables real-time decision-making and adaptive control strategies based on immediate sensor data, improving system efficiency and autonomy.

- **Machine Learning and Predictive Analytics:** Machine learning algorithms and predictive analytics have emerged as powerful tools for extracting meaningful insights from sensor data and predicting future plant health trends. By analyzing historical sensor data and correlating it with plant growth patterns and environmental conditions, machine learning models can identify hidden patterns, anomalies, and correlations that may not be apparent through traditional data analysis methods. These insights enable proactive plant care strategies, such as predictive watering schedules, early disease detection, and adaptive environmental control, ultimately improving plant health outcomes and resource efficiency.
- **Wireless Connectivity and IoT Ecosystem Integration:** Advancements in wireless communication technologies and IoT ecosystem integration have expanded the capabilities and interoperability of IOT-Based Smart Plant Monitoring Systems. Wireless protocols such as Bluetooth Low Energy (BLE), Zigbee, and LoRaWAN enable seamless connectivity between sensors, microcontrollers, and external devices, facilitating data exchange and remote-control functionalities. Furthermore, integration with existing IoT ecosystems, such as smart home platforms or agricultural management systems, enhances system interoperability and scalability, enabling broader applications and adoption.
- **User-Centric Design and Human-Machine Interaction:** Lastly, technological advancements in user-centric design and human-machine interaction have led to the development of more intuitive and user-friendly interfaces for IOT-Based Smart Plant Monitoring Systems. Mobile applications, web-based dashboards, and voice-activated assistants provide users with intuitive tools for monitoring plant health, adjusting settings, and receiving personalized recommendations. User-centric design principles focus on enhancing user experience, accessibility, and engagement, fostering greater adoption and usability of IOT-Based Smart Plant Monitoring Systems among diverse user groups.

Overall, these technological advancements and innovations represent significant strides in the development of IOT-Based Smart Plant Monitoring Systems, offering more robust, intelligent, and user-friendly solutions for optimizing plant health and fostering sustainable agriculture practices.

3.5 Applications and Use Cases

IOT-Based Smart Plant Monitoring Systems find diverse applications across various sectors, ranging from agriculture and horticulture to smart home automation and urban gardening. These systems offer innovative solutions for optimizing plant health, conserving resources, and enhancing productivity in both indoor and outdoor environments. Below are some key applications and use cases of IOT-Based Smart Plant Monitoring Systems:

- **Smart Agriculture and Precision Farming:** In agricultural contexts, IoT-based smart plant monitoring systems support precision farming by offering immediate insights into soil conditions, crop health, and environmental factors. Farmers utilize sensor networks throughout their fields to monitor soil moisture, temperature fluctuations, and nutrient levels, enabling precise strategies for irrigation, fertilization, and pest control. These systems enhance crop yields, reduce water and chemical usage, and mitigate environmental impacts, contributing to sustainable agriculture practices.
- **Indoor Plant Cultivation and Urban Gardening:** IOT-Based Smart Plant Monitoring Systems are widely used in indoor plant cultivation and urban gardening initiatives, where space constraints and environmental conditions pose challenges for plant care. By deploying sensor-equipped planters or hydroponic systems, urban gardeners can monitor and optimize growing conditions for herbs, vegetables, and ornamental plants. These systems enable remote monitoring and automated control of watering, lighting, and climate conditions, empowering urban dwellers to grow fresh produce and greenery in limited spaces.
- **Smart Greenhouse Management:** Greenhouse operations benefit significantly from IOT-Based Smart Plant Monitoring Systems, which provide comprehensive monitoring and control capabilities for managing temperature, humidity, light intensity, and CO_2 levels. Sensors distributed throughout the greenhouse collect real-time data on environmental parameters, enabling growers to optimize growing conditions for various crops. Automated actuators and controllers adjust ventilation, heating, and shading systems based on sensor readings, ensuring optimal growing conditions and maximizing crop yields.
- **Home Plant Care and Smart Gardening:** In residential settings, IOT-Based Smart Plant Monitoring Systems cater to home gardeners and plant enthusiasts seeking to maintain healthy indoor and outdoor plants. Smart planters equipped with sensors and microcontrollers enable users to monitor soil moisture, light exposure, and temperature levels remotely via mobile applications or web interfaces. These systems provide personalized recommendations for watering schedules, fertilizer applications, and pest control measures, helping users cultivate thriving plants with minimal effort.
- **Research and Education:** IOT-Based Smart Plant Monitoring Systems are valuable tools for research institutions, botanical gardens, and educational institutions conducting studies on plant physiology, ecology, and environmental science. Researchers can deploy sensor networks in controlled environments to investigate plant responses to environmental stressors, disease

outbreaks, and climate change impacts. These systems also serve as educational tools for teaching students about plant biology, data analytics, and sustainable agriculture practices, fostering hands-on learning experiences and scientific inquiry.

Through these applications and use cases, IOT-Based Smart Plant Monitoring Systems demonstrate their versatility and effectiveness in addressing diverse plant care needs across different sectors. By harnessing the power of IoT technology, these systems contribute to improved crop productivity, resource efficiency, and environmental sustainability, shaping the future of agriculture and plant cultivation practices.

3.6 Challenges and Limitations of IOT-Based Smart Plant Monitoring Systems

While IoT-based smart plant monitoring systems hold promise for enhancing plant health and productivity, they encounter several challenges and limitations that must be overcome to maximize their effectiveness. These issues arise from technological constraints, environmental complexities, and user-related factors. Key challenges include ensuring robust connectivity in diverse environments, maintaining sensor accuracy and reliability over time, integrating heterogeneous IoT devices seamlessly, managing large volumes of sensor data effectively, addressing cybersecurity concerns, and ensuring user-friendly interfaces that cater to varying levels of technical expertise. Overcoming these challenges is essential for realizing the full potential of IoT-based smart plant monitoring systems in modern agriculture and horticulture.

- **Sensor Accuracy and Reliability:** Ensuring the accuracy and reliability of sensor measurements is a primary challenge for IoT-based smart plant monitoring systems. Commercially available sensors often encounter issues such as calibration drift, signal interference, and sensitivity to environmental changes, which can result in inaccurate data readings. Addressing these challenges is crucial for enabling informed decision-making and implementing precise plant care strategies based on reliable data.
- **Data Overload and Processing Complexity:** IOT-Based Smart Plant Monitoring Systems generate vast amounts of sensor data, which can overwhelm processing and storage resources, particularly in large-scale deployments. Processing and analyzing this data in real-time pose significant computational challenges, requiring efficient algorithms and hardware architectures for data processing, storage, and transmission. Managing data overload and processing complexity is crucial for extracting meaningful insights and actionable recommendations from sensor data.
- **Interoperability and Compatibility:** IOT-Based Smart Plant Monitoring Systems often rely on heterogeneous sensor networks, communication protocols, and data formats, leading to interoperability and compatibility issues. Integrating diverse sensors and devices into a cohesive system can be challenging, requiring standardization efforts and middleware solutions to

facilitate data exchange and communication between different components. Ensuring interoperability and compatibility is essential for seamless integration and scalability of IOT-Based Smart Plant Monitoring Systems.

- **Power Consumption and Energy Efficiency:** Energy consumption is a critical consideration for IOT-Based Smart Plant Monitoring Systems, especially in remote or off-grid environments where power sources may be limited. Wireless sensor nodes and communication devices consume energy during data transmission, processing, and sensing operations, impacting system longevity and reliability. Designing energy-efficient sensor nodes, optimizing communication protocols, and implementing power management strategies are essential for maximizing system uptime and minimizing energy consumption.
- **Security and Privacy Concerns:** IOT-Based Smart Plant Monitoring Systems are vulnerable to security breaches, data tampering, and privacy violations, posing risks to plant health data integrity and user privacy. Protecting sensor data from unauthorized access, manipulation, and interception requires robust security measures, such as encryption protocols, access controls, and authentication mechanisms. Additionally, ensuring compliance with data privacy regulations and ethical standards is crucial for maintaining user trust and confidence in IOT-Based Smart Plant Monitoring Systems.
- **Cost and Affordability:** The cost of deploying and maintaining IOT-Based Smart Plant Monitoring Systems can be prohibitive for small-scale growers, hobbyists, and resource-constrained users. Components such as sensors, microcontrollers, and communication devices may incur upfront expenses, while ongoing maintenance and subscription fees for cloud services add to the overall cost of ownership. Finding cost-effective solutions and alternative deployment models, such as community-based sensor networks or open-source platforms, is essential for increasing accessibility and affordability of IOT-Based Smart Plant Monitoring Systems.

Addressing these challenges and limitations requires interdisciplinary collaboration, technological innovation, and user-centric design approaches. By overcoming these obstacles, IOT-Based Smart Plant Monitoring Systems can deliver more reliable, efficient, and user-friendly solutions for optimizing plant health and fostering sustainable agriculture practices.

3.7 Current Research and Future Directions for IOT-Based Smart Plant Monitoring Systems

In recent years, there has been a significant increase in research interest surrounding IoT-based smart plant monitoring systems. This surge is propelled by the rising demand for sustainable agricultural practices and advancements in sensor technology, data analytics, and communication protocols. Current research endeavors are primarily aimed at tackling existing challenges while exploring avenues to improve the functionality, efficiency, and user-friendliness of these systems. Moreover, researchers are actively exploring novel applications and use cases to broaden the scope of IoT-based smart plant monitoring systems and unleash their full potential across various domains.

One area of current research involves the development of advanced sensor technologies and sensing techniques tailored to plant monitoring applications. Researchers are exploring the use of innovative sensor modalities, such as hyperspectral imaging, spectroscopy, and nano sensors, to capture fine-grained plant health indicators and environmental parameters. These advanced sensors offer higher resolution, sensitivity, and specificity compared to traditional sensors, enabling more precise and comprehensive plant monitoring capabilities.

Another focus of current research is on improving data analytics and decision support mechanisms for IOT-Based Smart Plant Monitoring Systems. Researchers are developing machine learning algorithms, predictive models, and decision support systems to analyze sensor data, identify patterns, and generate actionable insights for plant care management. These data-driven approaches enable adaptive and proactive plant care strategies, such as predictive watering, disease prediction, and nutrient optimization, leading to improved crop yields and resource efficiency.

Furthermore, current research efforts aim to enhance the interoperability and scalability of IOT-Based Smart Plant Monitoring Systems through standardization and integration initiatives. Researchers are developing open-source platforms, interoperability frameworks, and data exchange protocols to facilitate seamless integration of heterogeneous sensor networks and interoperability with existing agricultural systems. These efforts enable cross-platform compatibility, data interoperability, and scalability, fostering collaboration and innovation in the field of plant monitoring technology.

Future research directions for IoT-based smart plant monitoring systems include exploring emerging technologies such as edge computing, blockchain, and quantum sensing. Edge computing enables real-time data processing at the network edge, reducing latency and bandwidth demands for plant monitoring applications. Blockchain technology enhances data security and transparency, ensuring integrity and auditability in distributed sensor networks. Quantum sensing promises superior sensitivity for detecting subtle changes in plant physiology and environmental conditions, offering new avenues for precision agriculture and plant phenotyping. Integrating these technologies aims to overcome current challenges, enhance system capabilities, and advance sustainable agriculture practices globally.

3.8 Summary

This chapter offers a comprehensive overview of IOT-Based Smart Plant Monitoring Systems, covering their background, components, advancements, applications, challenges, and future directions. It highlights the transformative impact of IoT technology on plant care practices and agricultural sustainability. Despite facing challenges such as sensor accuracy and data overload, ongoing research efforts aim to overcome these obstacles and unlock new opportunities for optimizing plant health and resource efficiency. Emerging technologies like edge computing and blockchain hold promise for further advancing plant monitoring systems, driving innovation in agriculture and environmental conservation. In Chapter 4, it will be discussed The Approach to IOT-Based Smart Plant Monitoring Systems.

CHAPTER 4

AN APPROACH TO IOT-BASED SMART PLANT MONITORING SYSTEMS

4.1 Introduction

Chapter 3 justified the suitability of IOT-Based Smart Plant Monitoring Systems and its key points. This chapter outlines a comprehensive framework for designing and implementing effective plant monitoring solutions leveraging IoT technology. This chapter aims to provide insights into the key components and considerations involved in developing IOT-Based Smart Plant Monitoring Systems. It discusses the hypothesis guiding the research, input sources, output formats, data processing methods, system features, target users, and concludes with a summary of the approach presented.

4.2 Hypothesis

The development and implementation of IOT-Based Smart Plant Monitoring Systems are guided by several hypotheses that shape the research methodology and approach.

- Integration Hypothesis: It is hypothesized that integrating IoT technology with plant monitoring systems will enhance the efficiency and effectiveness of plant care practices. By leveraging IoT sensors, data analytics, and remote-control capabilities, the system can provide real-time insights, personalized recommendations, and proactive interventions to optimize plant health.
- Data-Driven Hypothesis: The hypothesis posits that data-driven decision-making processes will lead to more accurate and informed plant care practices. By collecting and analyzing diverse environmental data, user preferences, and plant health metrics, the system can generate actionable recommendations tailored to the specific needs of individual plants and users.
- User-Centric Hypothesis: It is hypothesized that incorporating user-centric design principles will improve the usability and adoption of IOT-Based Smart Plant Monitoring Systems. By prioritizing user feedback, preferences, and requirements, the system can offer intuitive interfaces, customizable features, and seamless integration with existing workflows, thereby enhancing user satisfaction and engagement.
- Scalability Hypothesis: The hypothesis suggests that scalable deployment strategies will facilitate the widespread adoption and accessibility of IOT-Based Smart Plant Monitoring Systems. By designing modular and adaptable architectures, the system can accommodate varying user needs, environmental conditions, and resource constraints, enabling deployment across diverse settings and scales.

- Sustainability Hypothesis: It is hypothesized that promoting sustainability considerations will contribute to the long-term viability and impact of IOT-Based Smart Plant Monitoring Systems. By emphasizing energy efficiency, resource conservation, and environmental stewardship, the system can minimize its ecological footprint while maximizing its positive contribution to plant health and ecosystem resilience.

These hypotheses serve as guiding principles for the development, evaluation, and refinement of IOT-Based Smart Plant Monitoring Systems, providing a framework for testing assumptions, validating outcomes, and advancing the field of plant care technology. Through rigorous experimentation, iterative improvement, and interdisciplinary collaboration, these hypotheses aim to drive innovation and transformation in plant monitoring practices.

4.3 Input

In the context of IOT-Based Smart Plant Monitoring Systems, input refers to the diverse sources of data and information utilized to assess plant health, environmental conditions, and user preferences. These inputs serve as the foundation for generating insights, recommendations, and actionable interventions to optimize plant care practices. The input section explores the various sources of data integrated into the plant monitoring system, including environmental parameters, user preferences, and plant databases.

1. Environmental Parameters:

   Environmental parameters encompass a wide range of factors that influence plant health and growth, including soil moisture, light exposure, temperature, and humidity. IoT sensors deployed in the plant environment collect real-time data on these parameters, providing valuable insights into the conditions affecting plant well-being. By monitoring environmental parameters, the system can identify potential stressors, optimize growing conditions, and prevent adverse effects on plant health.

2. User Preferences:

   User preferences play a crucial role in tailoring plant care practices to meet individual needs and preferences. Through user input and interaction, the system gathers information about user preferences regarding plant species, care routines, and desired outcomes. By incorporating user preferences into the decision-making process, the system can personalize recommendations and interventions, enhancing user satisfaction and engagement.

3. Plant Databases:

   Plant databases provide valuable reference information about different plant species, their growth characteristics, and care requirements. By integrating plant databases into the monitoring system, users can access comprehensive information about specific plants, including optimal growing conditions, common pests and diseases, and recommended care practices. Plant databases serve as a valuable resource for guiding plant care decisions and troubleshooting issues related to plant health and maintenance.

By incorporating these diverse sources of input data, IOT-Based Smart Plant Monitoring Systems can generate comprehensive insights and recommendations tailored to the specific needs of individual plants and users. This holistic approach to input data collection enables the system to optimize plant care practices, promote plant health, and enhance the overall plant-keeping experience.

4.4 Output

The output of IOT-Based Smart Plant Monitoring Systems encompasses the various forms of information, insights, and recommendations generated by the system in response to input data and user interactions. These outputs serve to inform users about plant health status, provide actionable recommendations for care interventions, and facilitate informed decision-making to optimize plant care practices. The output section explores the key outputs produced by the plant monitoring system, including real-time plant data, recommendations, alerts, and notifications.

1. Real-time Plant Data:

   Real-time plant data comprises the continuous monitoring and measurement of various parameters related to plant health and environmental conditions. This includes data on soil moisture levels, light exposure, temperature, humidity, and other relevant factors collected by IoT sensors deployed in the plant environment. Real-time plant data provides users with up-to-date information about the status of their plants, enabling them to assess plant health trends, identify potential issues, and track the effectiveness of care interventions over time.

2. Recommendations:

   Recommendations are actionable insights and guidance provided by the plant monitoring system to users based on analysis of input data and predefined algorithms. These recommendations may include suggested watering schedules, optimal light exposure levels, temperature adjustments, and other care practices tailored to the specific needs of individual plants and user preferences. By leveraging data analytics and decision-making algorithms, the system can generate personalized recommendations to optimize plant health and promote optimal growth.

3. Alerts and Notifications:

   Alerts and notifications serve as timely notifications to users about critical events, anomalies, or changes in plant health status that require attention. These alerts may be triggered by deviations from predefined thresholds, such as abnormal soil moisture levels, extreme temperature fluctuations, or signs of pest infestation. By alerting users to potential issues in real-time, the system enables proactive intervention and preventive measures to mitigate risks and preserve plant health.

By delivering these outputs to users in a timely and accessible manner, IOT-Based Smart Plant Monitoring Systems empower users to make informed decisions, take proactive steps to optimize plant care practices, and ensure the health and well-being of their plants. The outputs provided by the system serve as valuable tools for enhancing plant care knowledge, facilitating efficient resource allocation, and promoting sustainable plant-keeping practices.

4.5 Process

The process of IOT-Based Smart Plant Monitoring Systems delineates the underlying methodologies and techniques involved in data collection, analysis, and decision-making within the system. This section provides insights into the sequential steps and processes through which input data are transformed into actionable outputs, including real-time plant data, recommendations, alerts, and notifications.

1. Data Collection:

   Data collection involves the systematic gathering of input data from diverse sources, including IoT sensors, user interactions, and plant databases. IoT sensors deployed in the plant environment continuously monitor environmental parameters such as soil moisture, light exposure, temperature, and humidity, collecting real-time data on plant health status and environmental conditions. User interactions, including preferences, feedback, and care activities, provide additional input data that inform the decision-making process. Plant databases serve as repositories of reference information about different plant species, growth characteristics, and care requirements, enriching the input data pool.

2. Data Preprocessing:

   Data preprocessing encompasses the cleaning, transformation, and normalization of raw input data to prepare it for analysis. This includes removing noise and outliers, handling missing values, and standardizing data formats to ensure consistency and reliability. Preprocessing techniques such as data imputation, feature scaling, and outlier detection are applied to enhance the quality and integrity of the input data, facilitating accurate analysis and decision-making.

3. Data Analysis:

   Data analysis involves the application of statistical, machine learning, and data mining techniques to extract meaningful insights and patterns from the input data. This includes exploratory data analysis to identify trends and correlations, predictive modeling to forecast future plant health outcomes, and anomaly detection to flag deviations from normal behavior. By leveraging data analytics algorithms and methodologies, the system can uncover hidden patterns, relationships, and dependencies within the input data, enabling informed decision-making and personalized recommendations.

4. Decision-making:

   Decision-making encompasses the process of synthesizing insights and recommendations derived from data analysis to generate actionable outputs for users. This involves applying predefined rules, algorithms, and decision criteria to interpret analyzed data and generate appropriate responses. Decision-making mechanisms may include rule-based systems, expert systems, and machine learning models that automate the generation of recommendations and interventions based on input data and user preferences. By streamlining decision-making processes, the system can provide timely and relevant outputs to users, enabling them to optimize plant care practices and promote plant health.

By following these sequential processes of data collection, preprocessing, analysis, and decision-making, IOT-Based Smart Plant Monitoring Systems transform raw input data into actionable outputs, facilitating informed decision-making and effective plant care practices. The systematic approach to data processing and analysis enhances the accuracy, reliability, and relevance of the outputs generated by the system, empowering users to optimize plant health and enhance the overall plant-keeping experience.

4.6 Features

The features section outlines the key characteristics and functionalities of IOT-Based Smart Plant Monitoring Systems that distinguish them from traditional plant care methods and technologies. These features encompass the unique capabilities and attributes of the system that enable it to monitor, analyze, and optimize plant health in both indoor and outdoor environments.

1. Comprehensive Monitoring:

   IOT-Based Smart Plant Monitoring Systems offer comprehensive monitoring capabilities that encompass a wide range of environmental parameters, including soil moisture, light exposure, temperature, and humidity. By deploying IoT sensors in the plant environment, the system continuously collects real-time data on these parameters, providing users with a holistic view of plant health status and environmental conditions.

2. User-Friendly Interface:

   The system features a user-friendly interface that facilitates intuitive interaction and accessibility for users of all levels of expertise. Through the interface, users can easily access real-time plant data, personalized recommendations, and actionable insights, enabling informed decision-making and proactive plant care interventions. The interface may include visualizations, dashboards, and customizable settings to enhance usability and user satisfaction.

3. Remote Control:

   IOT-Based Smart Plant Monitoring Systems enable remote control capabilities that allow users to monitor and manage plant care activities from anywhere, at any time. Through the system's interface, users can remotely adjust watering schedules, modify light exposure levels, and monitor plant health metrics, ensuring optimal conditions for plant growth and well-being even when they are away from the plant environment.

4. Data-Driven Recommendations:

   The system generates data-driven recommendations based on analysis of input data and predefined algorithms. These recommendations may include suggested watering schedules, optimal light exposure levels, temperature adjustments, and other care practices tailored to the specific needs of individual plants and user preferences. By leveraging data analytics and decision-making algorithms, the system provides personalized guidance to optimize plant health and promote optimal growth.

5. Alerts and Notifications:

   IOT-Based Smart Plant Monitoring Systems provide timely alerts and notifications to users about critical events, anomalies, or changes in plant health status that require attention. These alerts may be triggered by deviations from predefined thresholds, such as abnormal soil moisture levels, extreme temperature fluctuations, or signs of pest infestation. By alerting users to potential issues in real-time, the system enables proactive intervention and preventive measures to mitigate risks and preserve plant health.

6. Sustainability Considerations:

   The system incorporates sustainability considerations to minimize environmental impact and promote eco-friendly plant care practices. This may include energy-efficient sensor designs, water-saving irrigation strategies, and environmentally friendly materials used in system components. By prioritizing sustainability, the system aims to reduce resource consumption, minimize ecological footprint, and promote responsible plant-keeping practices.

These features collectively contribute to the effectiveness, efficiency, and usability of IOT-Based Smart Plant Monitoring Systems, enabling users to optimize plant health, promote sustainability, and enhance the overall plant-keeping experience. By leveraging advanced technology and innovative functionalities, these systems represent a significant advancement in plant care practices, offering users unprecedented insights and control over their plants' well-being.

4.7 Users

The users of IOT-Based Smart Plant Monitoring Systems delineate the diverse stakeholders and end-users who interact with the system and benefit from its functionalities. These users encompass a broad spectrum of individuals, including plant enthusiasts, horticulturalists, researchers, and agricultural professionals, each with unique needs, preferences, and objectives related to plant care and management.

1. Plant Enthusiasts:

   Plant enthusiasts represent a significant user group of IOT-Based Smart Plant Monitoring Systems, comprising individuals who cultivate plants for hobby, leisure, or aesthetic purposes. These users may include home gardeners, indoor plant enthusiasts, and amateur botanists who seek to enhance their plant care knowledge, optimize growing conditions, and nurture healthy, thriving plants. For plant enthusiasts, the system provides valuable insights, recommendations, and control capabilities that empower them to care for their plants effectively and cultivate rewarding plant-keeping experiences.

2. Horticulturalists:

   Horticulturalists and professional growers constitute another important user segment of IOT-Based Smart Plant Monitoring Systems, encompassing individuals involved in commercial plant cultivation, landscaping, and horticultural research. These users rely on advanced plant care technologies to optimize crop yields, maintain landscape aesthetics, and conduct scientific research on plant physiology and growth patterns. For horticulturalists, the system offers sophisticated monitoring and management capabilities that enable them to monitor large-scale plantings, optimize growing conditions, and maximize plant health and productivity.

3. Researchers:

   Researchers and academics engaged in plant science, agronomy, and environmental studies utilize IOT-Based Smart Plant Monitoring Systems as valuable tools for conducting scientific research, experimentation, and data analysis. These users leverage the system's data collection, analysis, and visualization capabilities to study plant responses to environmental stimuli, investigate plant growth dynamics, and develop novel plant care strategies. By providing access to real-time plant data and insights, the system facilitates scientific inquiry and contributes to the advancement of plant science and agricultural innovation.

4. Agricultural Professionals:

Agricultural professionals, including farmers, agronomists, and agricultural consultants, rely on IOT-Based Smart Plant Monitoring Systems to optimize crop management practices, improve resource efficiency, and maximize farm productivity. These users utilize the system's monitoring and analysis capabilities to observe crop health, evaluate field conditions, and base data-driven decisions on irrigation, fertilization, and pest management. IoT technology integration into agricultural operations empowers professionals to improve crop yields, lower input expenses, and advocate for sustainable farming practices.

By catering to the diverse needs and requirements of these user groups, IOT-Based Smart Plant Monitoring Systems play a pivotal role in revolutionizing plant care practices, promoting sustainability, and enhancing the well-being of plants in both residential and commercial settings. Through user-centric design and innovative functionalities, these systems empower users to cultivate thriving plants, foster a deeper connection with nature, and contribute to the advancement of plant science and agricultural innovation.

4.8 Summary

This chapter provides a comprehensive overview of the key elements and functionalities inherent to IOT-Based Smart Plant Monitoring Systems. Beginning with an introduction to the chapter's scope, the subsequent sections delve into the hypothesis, input, output, process, features, and users of these systems. The chapter highlights the systematic approach to plant monitoring, emphasizing the integration of IoT technology, data analysis, and user-centric design to facilitate informed decision-making and optimize plant care practices. By considering the diverse needs and perspectives of users, from plant enthusiasts to agricultural professionals, IOT-Based Smart Plant Monitoring Systems offer a holistic solution to enhance plant health, promote sustainability, and advance the field of plant science and horticulture. Chapter 5 describes the Design of the implemented system and its features.

CHAPTER 5

DESIGN

5.1 Introduction

Chapter 4 provided an in-depth exploration of the approach to IOT-Based Smart Plant Monitoring Systems. This chapter presents a detailed overview of the architecture and components comprising the IOT-Based Smart Plant Monitoring System. We aim to elucidate the top-level architecture, integration of IoT technology, functionalities, circuit diagram illustrating sensor connections, user interface, and a comprehensive summary of the design approach. Each section provides insights into the system's design principles, technological components, interconnections, algorithms, and equations used, laying the foundation for the subsequent implementation and evaluation stages of the research. This systematic approach highlights the development of an effective and user-friendly IoT-based plant monitoring solution.

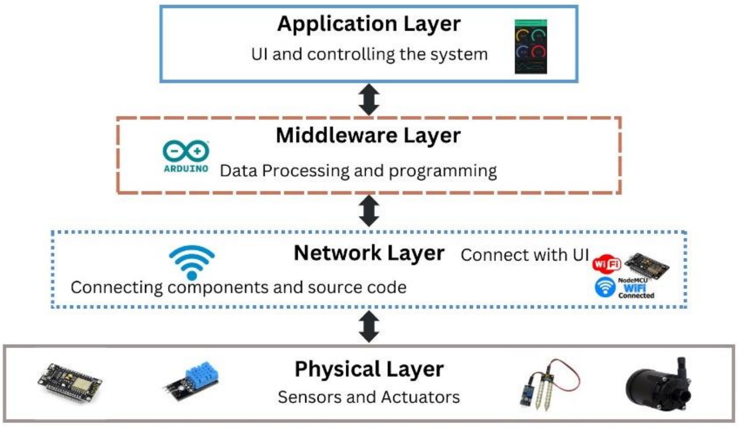
5.2 Top-level Architecture

The top-level architecture of the IoT-Based Smart Plant Monitoring System encompasses essential modules: sensor nodes, a data processing unit, a user interface, and cloud integration. Sensor nodes are strategically placed in the plant environment to gather real-time data on crucial environmental factors like soil moisture, light exposure, temperature, and humidity. These nodes then transmit the collected data to the data processing unit, which analyzes and interprets it to generate actionable insights and recommendations for plant care. The user interface provides a platform for users to interact with the system, visualize plant data, and remotely manage plant care settings. Furthermore, cloud integration supports data storage, remote accessibility, and scalability, ensuring the system operates seamlessly and remains easily accessible.

Here, we use the similar architecture like five-layer architecture for IOT. But here we only use four layers since we are not considering the business layer at this phase. By basic architecture it’s defined how the system is designed and by architecture diagram it is described how the components are arranged into certain layers.

Figure 5.1

Architecture Diagram of the designed system



Physical Layer

This layer includes all physical components such as ESP8266 microcontroller, soil moisture sensor, rain sensor, PIR motion sensor, DHT 11 sensor, relay module, and DC water pump. It represents the physical structure and setup of the system.

Network Layer

This layer describes the network protocols and techniques used for communication. Wi-Fi is the primary communication technique, supplemented by messaging and email protocols when necessary.

Middleware Layer

This layer incorporates the programming environment (Arduino IDE) and data processing algorithms. It is responsible for processing sensor data and controlling actuators based on predefined thresholds and logic.

Application Layer

This layer represents the user interface of the system. The Blynk application is used for monitoring and controlling the system, offering both mobile and web interfaces for user convenience.

5.3 IOT Technology

This provides an in-depth exploration of the underlying technologies utilized in the IOT-Based Smart Plant Monitoring System. This section aims to elucidate the key components, protocols, and communication mechanisms that enable seamless connectivity, data exchange, and interoperability within the system. By examining the foundational principles of IoT technology, including sensor networks, communication protocols, and cloud computing, this section establishes the technological framework upon which the plant monitoring system is built.

At the heart of the IoT technology stack are sensor nodes, essential for acquiring data in plant environments. These nodes incorporate diverse sensors like moisture, light, temperature, and humidity sensors to capture real-time environmental data. The choice of sensors is tailored to meet specific monitoring needs and environmental conditions within the plant ecosystem.

Moreover, communication protocols are crucial for enabling seamless data transmission and interoperability within the IoT ecosystem. Widely adopted protocols such as Wi-Fi, Bluetooth Low Energy (BLE), and Zigbee facilitate wireless communication among sensor nodes, data processing units, and cloud infrastructure components. These protocols ensure efficient data exchange, enabling real-time monitoring and control of IoT-based systems in diverse environments. These protocols enable efficient data exchange, seamless integration, and real-time monitoring across distributed sensor networks.

Additionally, cloud computing technologies are utilized to store, process, and analyze the large volumes of data generated by the IoT-Based Smart Plant Monitoring System. Cloud platforms provide scalable storage solutions, computational resources, and analytics tools that enable advanced data processing, machine learning algorithms, and predictive analytics. By harnessing the power of the cloud, the plant monitoring system can efficiently manage and derive actionable insights from sensor data, facilitating informed decision-making and optimizing plant care practices.

5.4 IOT-Based Smart Plant Monitoring Systems

This section explores current systems and solutions in the field of IoT-based plant monitoring, aiming to offer insights into the latest technologies, methodologies, and applications used. Through the examination of prominent examples and case studies, it highlights various approaches and functionalities of IoT-Based Smart Plant Monitoring Systems, providing valuable insights for designing and implementing the proposed system.

Many IoT-Based Smart Plant Monitoring Systems have been developed to tackle challenges in plant care, optimize growing conditions, and improve plant health in diverse environments, including indoor and outdoor settings. These systems typically consist of sensor networks, data processing units, user interfaces, and cloud integration, enabling real-time monitoring, data analysis, and remote-control functionalities.

One notable example is the "Smart Plant Monitoring System" developed by researchers [25]. Another system developed by researchers utilizes a network of IoT sensors to monitor soil moisture, temperature, and light exposure specifically in indoor plant environments. [3]. The collected data is transmitted to a central processing unit, where it undergoes analysis to derive insights into plant health and growth patterns. This system includes a user-friendly interface that enables plant enthusiasts to access real-time plant data, receive personalized recommendations, and remotely control watering and lighting settings. [28].

Another noteworthy systems developed by researchers integrate IoT technology with machine learning algorithms to provide intelligent plant care recommendations based on environmental data and user preferences [23]. Those utilizes advanced data analytics and predictive modeling to optimize plant health, conserve water resources, and minimize environmental impact. The platform offers a range of features, including automated irrigation scheduling, nutrient management, and disease detection, making it a comprehensive solution for plant enthusiasts and horticulturalists [13].

Furthermore, commercial solutions such as Kisters and Smart Plant Monitoring shystem by Robocraze offer off-the-shelf IoT devices for plant monitoring, catering to both casual gardeners and professional growers. These systems leverage wireless sensor networks and smartphone apps to deliver real-time plant insights, watering reminders, and customized care instructions, democratizing access to advanced plant monitoring technology [14].

5.5 Equations and Algorithms

This section details the key equations and algorithms used in the IOT-Based Smart Plant Monitoring System to process sensor data and derive actionable insights for plant care.

Soil Moisture Calculation:

To determine the soil moisture level, the system uses the following equation:

$$\text{Soil Moisture (\%)} = \left(\frac{\text{Raw Sensor Value}}{\text{Maximum Sensor Value}}\right) \times 100$$

Description:

- Raw Sensor Value: The current reading from the soil moisture sensor.
- Maximum Sensor Value: The highest possible reading the sensor can provide.
- This calculation converts the raw sensor value to a percentage, indicating the moisture level in the soil.

Temperature and Humidity Calculation:

Using DHT11 sensor readings:

$$\text{Temperature (°C)} = \text{Raw Temperature Value}$$

$$\text{Humidity (\%)} = \text{Raw Humidity Value}$$

Description:

- Raw Temperature Value: Direct reading from the temperature sensor.
- Raw Humidity Value: Direct reading from the humidity sensor.
- These calculations provide straightforward temperature and humidity readings from the DHT11 sensor.

Additional Algorithms:

Light Intensity Calculation:

For light intensity measurement using a light sensor (e.g., LDR or photodiode), the system calculates:

$$\text{Light Intensity (Lux)} = \left(\frac{\text{Raw Light Sensor Value}}{\text{Maximum Light Sensor Value}}\right) \times \text{Calibration Constant}$$

Description:

- Raw Light Sensor Value: Current reading from the light sensor.
- Maximum Light Sensor Value: The highest possible reading the sensor can provide.
- Calibration Constant: A value determined during sensor calibration to convert raw data to lux.

Data Normalization Algorithm:

To standardize sensor data for comparison and processing:

$$\text{Normalized Value} = \left(\frac{\text{Current Value} - \text{Minimum Value}}{\text{Maximum Value} - \text{Minimum Value}}\right)$$

Description:

- Current Value: The current reading from the sensor.
- Minimum Value: The minimum possible reading from the sensor.
- Maximum Value: The maximum possible reading from the sensor.
- This normalization ensures that all sensor readings are scaled to a consistent range (e.g., 0 to 1).

Irrigation Control Algorithm:

An algorithm to automate irrigation based on soil moisture levels:

```
if soil_moisture < threshold_moisture_level:
    activate_water_pump()
else:
    deactivate_water_pump()
```

Description:

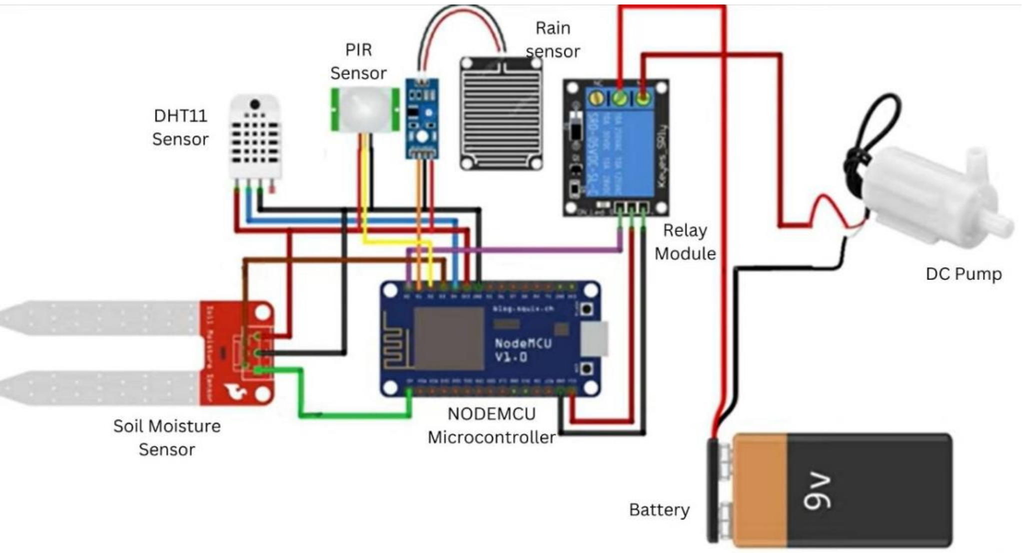
- soil_moisture: Current soil moisture reading.
- threshold_moisture_level: Predefined moisture level threshold for irrigation.
- This algorithm activates or deactivates the water pump based on soil moisture readings.

5.6 Circuit Diagram

This diagram visually represents the hardware architecture and connectivity of the implemented IoT-Based Smart Plant Monitoring System. It illustrates how components such as sensors, microcontrollers, actuators, and power sources are interconnected, providing a clear view of the system's physical layout and functionality. Stakeholders can use the circuit diagram to understand the wiring configuration, sensor placements, and data flow within the system, which aids in troubleshooting, maintenance, and future development efforts.

Figure 5.2

The Circuit Diagram of the system



5.7 User interface

In this system, the user interface is developed using the Arduino IDE for coding and the Blynk app for monitoring plant parameters remotely. The Arduino IDE provides a familiar programming environment for writing code to control and communicate with the hardware components of the system, including sensors, microcontrollers, and actuators. Through the Arduino IDE, users can customize the behavior of the system, configure sensor readings, and define thresholds for automated actions such as watering and lighting adjustments.

Additionally, the Blynk app serves as a user-friendly interface for remotely monitoring plant parameters and receiving real-time updates on plant health status. Blynk offers a drag-and-drop interface for creating customizable dashboards and widgets, allowing users to visualize sensor data, set alarms, and control system settings from their smartphones or tablets. By leveraging the Blynk platform, users can access the plant monitoring system from anywhere with an internet connection, enabling convenient and on-the-go management of plant care tasks.

5.8 Summary

This chapter presents a comprehensive overview of the IOT-Based Smart Plant Monitoring System, covering its architecture, technology, and user interface. Through the top-level architecture, IoT technology exploration, and discussion of existing systems, the chapter highlights the system's components, connectivity protocols, and innovative applications. The inclusion of a circuit diagram provides a visual representation of the hardware layout, while the description of the user interface emphasizes the use of Arduino IDE and Blynk app for coding and monitoring, respectively. Implementation of the system and further details discuss in the chapter 6.

CHAPTER 6

IMPLEMENTATION

6.1 Introduction

Chapter 5 presented a comprehensive overview of the IOT-Based Smart Plant Monitoring System, covering its architecture, technology, and user interface. This chapter provides a detailed account of the practical realization of the IOT-Based Smart Plant Monitoring System discussed in earlier chapters. This chapter encompasses various aspects of the implementation process, including the choice of operating system, platforms, and cloud services, as well as the hardware and software components, algorithms, and class diagrams involved in the plant monitoring system. Additionally, it explores the integration of IoT technologies, the design and development of the plant monitoring system, the user interface, and concludes with a summary of the implementation approach and outcomes. Each section sheds light on the technical aspects of bringing the IOT-Based Smart Plant Monitoring System from concept to reality, emphasizing the practical considerations and challenges encountered during the implementation phase.

6.2 Overall implementation

The implementation of the IOT-Based Smart Plant Monitoring System involves several key considerations, including the choice of operating system (OS), platform, and cloud services. These elements play a crucial role in determining the functionality, performance, and scalability of the system.

For the operating system, we opted for a lightweight and versatile solution that could run on the selected hardware platform while providing robust support for networking and sensor interfacing. After careful evaluation, we chose to utilize the Arduino programming environment, which offers compatibility with a wide range of microcontrollers and provides ample libraries for sensor integration and communication protocols.

In terms of platform, we leveraged the NodeMCU development board, which combines the capabilities of the ESP8266 Wi-Fi module with the Arduino IDE, allowing for seamless development and deployment of IoT applications. The NodeMCU platform provides built-in support for Wi-Fi connectivity, making it ideal for wireless communication and remote monitoring applications.

Additionally, we utilized cloud services to facilitate data storage, processing, and remote access to the plant monitoring system. By leveraging cloud platforms such as Blynk cloud or Tuniol, we were able to securely store sensor data, perform real-time analytics, and provide users with access to the monitoring system from anywhere with an internet connection.

Overall, the implementation of the IOT-Based Smart Plant Monitoring System required careful consideration of the OS, platform, and cloud services to ensure seamless integration, reliable performance, and scalability. By selecting appropriate technologies and platforms, we were able to develop a robust and versatile monitoring system capable of meeting the diverse needs of plant enthusiasts and horticulturalists.

6.3 Plant Monitoring System implementation

The implementation of the IOT-Based Smart Plant Monitoring System involves the integration of hardware, software, algorithms, and class diagrams to create a cohesive and functional solution for monitoring plant health and environmental conditions.

The hardware components of the plant monitoring system comprise various sensors designed to measure critical environmental parameters essential for plant health. These include the PIR sensor for motion detection, DHT11 sensor for monitoring temperature and humidity, soil moisture sensor for measuring soil moisture levels, and a rain sensor for detecting precipitation. These sensors are interfaced with the NodeMCU development board, which acts as the central processing unit responsible for collecting data from the sensors. The NodeMCU then transmits this data to the cloud infrastructure for analysis and storage. Additionally, the system includes a DC pump and relay module used for automated watering of plants based on the sensor data, ensuring optimal soil moisture levels for plant growth.

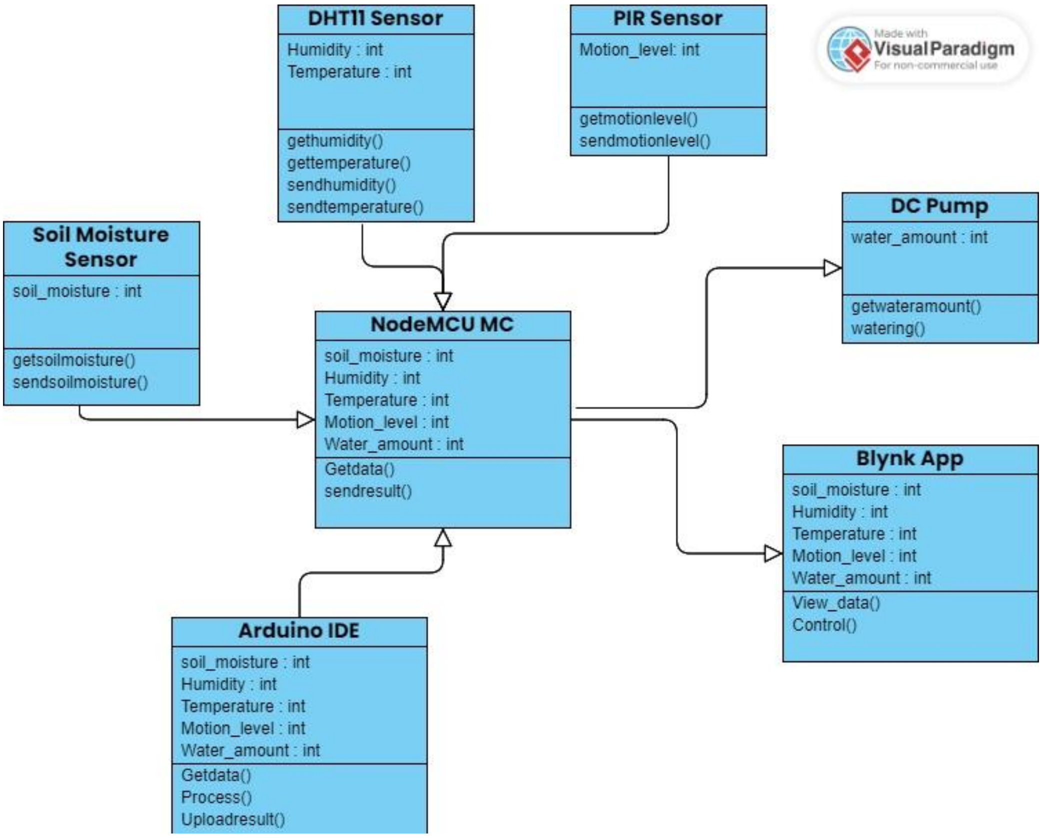
On the software side, the plant monitoring system is programmed using the Arduino IDE, which allows for the development of firmware to control sensor readings, data transmission, and user interaction. The firmware is responsible for collecting sensor data at regular intervals, processing it according to predefined algorithms, and transmitting the data to the cloud for further analysis.

The algorithms implemented in the firmware are designed to interpret sensor data and provide insights into plant health and environmental conditions. These algorithms may include threshold-based alerts for detecting abnormal conditions, predictive analytics for forecasting plant growth, and optimization routines for adjusting watering schedules based on sensor readings.

The class diagram for the plant monitoring system illustrates the relationship between different software components and their interactions. It typically includes classes for sensor interfaces, data processing modules, communication protocols, and user interfaces. By visualizing the structure of the software components and their dependencies, the class diagram helps developers understand the system architecture and facilitate code organization and maintenance.

Figure 6.1

The Class Diagram of the system



6.4 IOT Technologies

The implementation of the IOT-Based Smart Plant Monitoring System relies on a thorough understanding of the underlying technologies driving connectivity, data exchange, and interoperability within the system. This section delves into the key components, protocols, and communication mechanisms essential for seamless operation and integration.

At the core of the IoT technology stack are sensor nodes, acting as primary data acquisition units strategically positioned throughout the plant environment. Equipped with an array of sensors including moisture, light, temperature, and humidity sensors, these nodes capture real-time environmental data tailored to the specific monitoring requirements and conditions of the plant ecosystem.

In conjunction with sensor nodes, communication protocols serve as vital conduits for data transmission and interoperability within the IoT ecosystem. Embracing protocols like Wi-Fi, Bluetooth Low Energy (BLE), and Zigbee, the system ensures efficient wireless communication among sensor nodes, data processing units, and cloud infrastructure. This facilitates seamless data exchange, integration, and real-time monitoring across distributed sensor networks.

Furthermore, cloud computing technologies play a pivotal role in managing the extensive data generated by the plant monitoring system. Leveraging scalable storage solutions, computational resources, and analytics tools offered by cloud platforms, the system can effectively store, process, and analyze sensor data. This enables advanced data processing, machine learning algorithms, and predictive analytics, empowering informed decision-making and optimization of plant care practices.

6.5 IOT-Based Smart Plant Monitoring System

The IoT-Based Smart Plant Monitoring System integrates interconnected sensor nodes, communication protocols, cloud infrastructure, and user interfaces to facilitate comprehensive monitoring, analysis, and management of plant health parameters. Key hardware components include moisture sensors, light sensors, temperature sensors, and humidity sensors strategically deployed to capture real-time environmental data. These sensor nodes communicate wirelessly via protocols such as Wi-Fi, Bluetooth Low Energy (BLE), or Zigbee, enabling efficient data transmission to either a central processing unit or directly to a cloud server for processing and storage. This interconnected system supports automated and informed decision-making in plant care, ensuring optimal conditions for plant growth and health.

On the software front, the system incorporates algorithms for data processing, analysis, and decision-making, aimed at extracting actionable insights from the collected sensor data. Machine learning algorithms may be employed for predictive analytics, anomaly detection, and automated decision-making, enhancing the system's intelligence and responsiveness. Additionally, user interfaces, either web-based or mobile applications, provide intuitive dashboards for users to visualize plant health metrics, receive alerts and notifications, and remotely control the monitoring system.

The implementation of the IOT-Based Smart Plant Monitoring System is a multifaceted endeavor that involves hardware design, software development, algorithm implementation, and system integration. Through meticulous planning, prototyping, and testing, the system aims to deliver robust, reliable, and user-friendly functionality for monitoring and optimizing plant health in both indoor and outdoor environments. This chapter elucidates the technical details and practical considerations involved in bringing the IOT-Based Smart Plant Monitoring System from concept to reality, highlighting the innovative solutions and technological advancements employed to address the challenges of modern plant care practices.

6.6 User interface

In this implementation, the user interface (UI) is developed using the Arduino IDE for coding and the Blynk app for monitoring. The Arduino IDE offers a familiar and versatile platform for programming the hardware components of the IOT-Based Smart Plant Monitoring System, allowing for the implementation of custom functionalities and algorithms. On the other hand, the Blynk app provides a user-friendly interface for remotely monitoring plant health metrics, receiving alerts, and controlling the system parameters from any location with internet access. By leveraging these tools, users can conveniently access and manage the plant monitoring system, enhancing the overall user experience and usability of the solution.

Figure 6.2

Blynk for controlling the system -Mobile Interface

Figure 6.3

Blynk for controlling the system – Web Dashboard

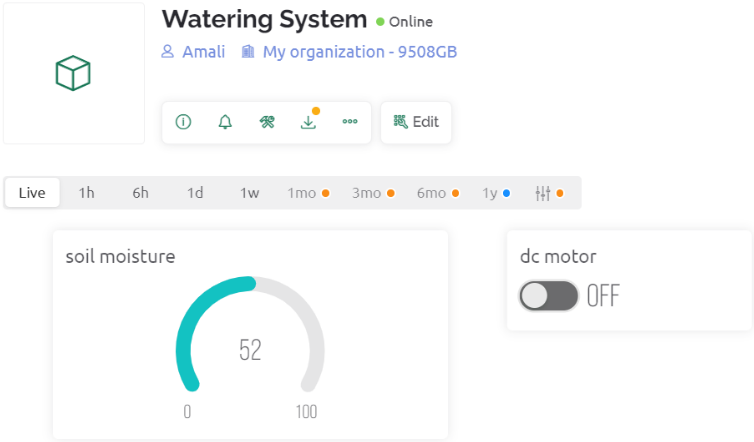
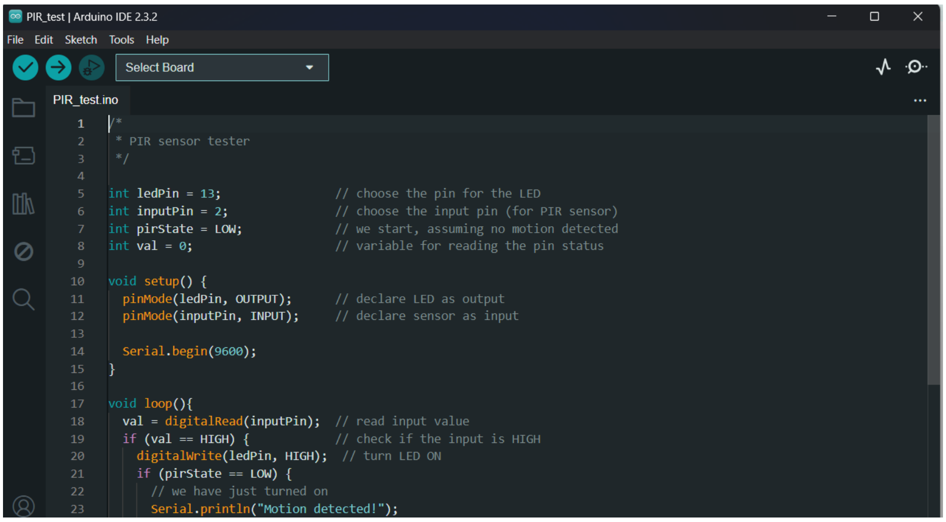


Figure 6.4

Arduino – The coding IDE for the system

Figure 6.5

Arduino IDE– Coding interface



6.7 Summary

The IOT-Based Smart Plant Monitoring System is realized through the integration of hardware and software components, algorithms, and user interfaces. This chapter provides a comprehensive overview of the system architecture, technological implementation, and practical considerations involved in bringing the system from concept to reality. Through meticulous planning and execution, the implementation phase aims to deliver a robust, reliable, and user-friendly solution for monitoring and optimizing plant health in indoor and outdoor environments. In chapter 7 Evaluation of the system and research work will be discussed in detail.

CHAPTER 7

EVALUATION

7.1 Introduction

Chapter 6 provided a detailed account of the practical realization of the IOT-Based Smart Plant Monitoring System discussed in earlier chapters. In this chapter, we assess how well the IOT-Based Smart Plant Monitoring System works. We involve participants in tests and carefully design experiments to understand the system's performance. By preparing specific test cases based on different features and user needs, we explore how the system responds. We analyze the results to see what works well and where improvements are needed. Finally, we summarize our findings to highlight what we've learned and what could be done next.

7.2 Participants

Here, the details of the individuals or groups involved in testing the IOT-Based Smart Plant Monitoring System is included. This may include plant enthusiasts, horticulturalists, or individuals with expertise in IoT technology. Their roles, demographics, and any specific criteria used for selection were outlined here. Additionally, it is described how participants were recruited or engaged to participate in the testing process, ensuring a diverse and representative sample for comprehensive evaluation. Through the involvement of participants, it was aimed to gather valuable feedback and insights into the usability, functionality, and effectiveness of the system in real-world scenarios.

7.3 Experimental design

Here, we meticulously outline the framework guiding our evaluation of the IOT-Based Smart Plant Monitoring System. Our approach is rooted in clearly defined research objectives and hypotheses, which serve as guiding principles throughout the testing process. These objectives delineate the specific aspects of the system's performance that we seek to investigate, such as its accuracy in measuring environmental parameters or its effectiveness in providing actionable insights for plant care. By establishing these objectives upfront, it is ensured that our evaluation remains focused and aligned with the overarching goals of the research.

Simulator was employed to replicate real-world conditions and generate synthetic datasets for testing purposes. The simulator encompasses various factors that influence plant health and growth, including soil moisture levels, rain detection, motion detection, temperature, and humidity. All the datasets generated by relevant sensors of these factors were converted into int values and those values were analyzed according to our requirements and control the system. Data sets recorded in the Blynk application were used for the analyzing and controlling purpose. These factors are meticulously controlled and manipulated to simulate different environmental scenarios and plant conditions, allowing us to assess the system's performance under diverse circumstances. By incorporating realistic environmental factors into the dataset, it was ensured that our evaluation captures the complexities of plant care and monitoring in real-world settings, enhancing the reliability and validity of our findings. As a initial step it was tested both soil moisture and rain detection to control the watering, and latterly step by step other sensors also added and checked with the integrated system. Additionally, the simulator facilitates the generation of large-scale datasets, enabling comprehensive testing across a wide range of scenarios and use cases by using various sensors and actuators.

Moreover, our experimental design incorporates rigorous methodologies to minimize bias and confounding factors that could influence the results. We carefully select and control variables relevant to the evaluation, such as the types of plants studied, environmental conditions, and testing procedures. Additionally, we implement standardized protocols for data collection, ensuring consistency and reliability across experiments. Ethical considerations, including participant consent and data privacy, are paramount throughout the design process, reflecting our commitment to upholding ethical standards in research. Through this systematic and principled approach to experimental design, we aim to generate robust and actionable insights into the performance of the IOT-Based Smart Plant Monitoring System.

7.4 Testing Strategy (preparatory work)

We outline the preparatory work undertaken to ensure the systematic and effective execution of our evaluation process. This includes defining the scope and objectives of the testing, as well as establishing clear criteria for assessing the performance of the IOT-Based Smart Plant Monitoring System. We conduct a thorough review of existing literature and industry best practices to inform our testing approach and identify relevant benchmarks for comparison. Additionally, we develop a detailed testing protocol that outlines the specific steps, procedures, and methodologies to be followed during the evaluation.

Furthermore, we carefully select and prepare the testing environment to replicate real-world conditions as closely as possible. This involves setting up the necessary hardware and software components of the plant monitoring system, configuring sensor networks, and calibrating instrumentation for accurate data collection. We also conduct pilot tests or feasibility studies to validate the experimental setup and identify any potential challenges or limitations that may arise during testing. By investing time and effort in thorough preparatory work, we aim to ensure the reliability, validity, and rigor of our evaluation process, ultimately enhancing the credibility and usefulness of the findings obtained.

7.5 Test cases (based on features/users/input/output)

In the evaluation of the IOT-Based Smart Plant Monitoring System, we devise a series of test cases based on the system's key features, target users, and input-output functionalities. These test cases are designed to comprehensively assess the system's performance across various scenarios and use cases, allowing us to identify strengths, weaknesses, and areas for improvement.

For features-based test cases, we evaluate each core functionality of the system, including data collection, analysis, and user interface interaction. This entails testing the accuracy and reliability of sensor readings, the effectiveness of data analysis algorithms in deriving actionable insights, and the usability of the user interface in accessing and interpreting plant health information. Additionally, we assess the system's responsiveness to user commands and its ability to generate timely alerts and notifications in response to detected anomalies or critical events.

In parallel, we develop test cases tailored to different user profiles, such as plant enthusiasts, horticulturalists, and commercial growers. These test cases simulate the diverse needs and preferences of end-users, ensuring that the system adequately addresses their requirements and expectations. For example, we evaluate the system's ability to accommodate varying plant species, growth stages, and environmental conditions, as well as its scalability and flexibility to support different deployment scenarios, from home gardens to commercial greenhouses.

Furthermore, we devise test cases that focus on input-output functionalities, assessing the system's ability to process and respond to different types of inputs and generate appropriate outputs. This includes testing the system's compatibility with various sensor types and data formats, its robustness in handling noisy or incomplete data, and its capacity to deliver personalized recommendations and insights based on user preferences and historical data. Through these comprehensive test cases, we aim to provide a holistic evaluation of the IOT-Based Smart Plant Monitoring System, highlighting its strengths and identifying areas for further refinement and enhancement.

Here are the relevant and suitable test cases for evaluating the IOT-Based Smart Plant Monitoring System:

1. Sensor and Board Accuracy Test:

   Verify the accuracy of sensor readings for critical environmental parameters (e.g., soil moisture, humidity, motion, temperature).

   Evaluate the consistency and reliability of sensor measurements over time and under different environmental conditions.

2. Data Analysis Algorithm Test:

   Assess the effectiveness of data analysis algorithms in deriving actionable insights from sensor data.

Verify the algorithm's ability to detect patterns, anomalies, and trends indicative of plant health status and environmental conditions.

3. User Interface Usability Test:

   Evaluate the ease of use and intuitiveness of the user interface for accessing plant health information and controlling system functionalities.

   Test the responsiveness and efficiency of user interactions, such as navigating menus, viewing data visualizations, and adjusting settings.

4. Remote Control Functionality Test:

   Assess the system's responsiveness to remote commands for controlling actuators (e.g., watering pumps, LED lights) and adjusting environmental parameters.

   Verify the reliability of remote-control functionalities over different communication channels (e.g., Wi-Fi, cellular network).

5. Alert and Notification Test:

   Evaluate the system's ability to generate timely alerts and notifications for predefined events and thresholds (e.g., low soil moisture, high temperature).

   Test the delivery mechanism and format of alerts, ensuring clarity and accessibility for end-users.

6. User Profile Simulation Test:

   Simulate different user profiles (e.g., plant enthusiasts, horticulturalists, commercial growers) to assess the system's suitability and relevance to diverse user needs and preferences.

   Evaluate the system's adaptability to varying plant species, growth stages, and environmental contexts, considering factors such as plant-specific requirements and user expertise levels.

7. Input-Output Compatibility Test:

   Test the system's compatibility with various sensor types and data formats, ensuring seamless integration and interoperability with external devices and data sources.

   Assess the system's ability to process and analyze different types of input data (e.g., analog, digital) and generate relevant output responses (e.g., recommendations, alerts) accordingly.

7.6 Results

The results of the evaluation of the IOT-Based Smart Plant Monitoring System are as follows:

1. Sensor and Board Accuracy Test:

The sensor accuracy test revealed that the sensors consistently provided accurate readings for critical environmental parameters such as soil moisture, rain detection, motion detection, temperature, and humidity. However, slight variations were observed based on environmental conditions and sensor calibration.

All the sensors tested separately with using some LEDs to check the accuracy and performance of each. Following are some of output captures when testing each sensor.

Figure 7.1

Soil moisture sensor testing with Blynk Cloud

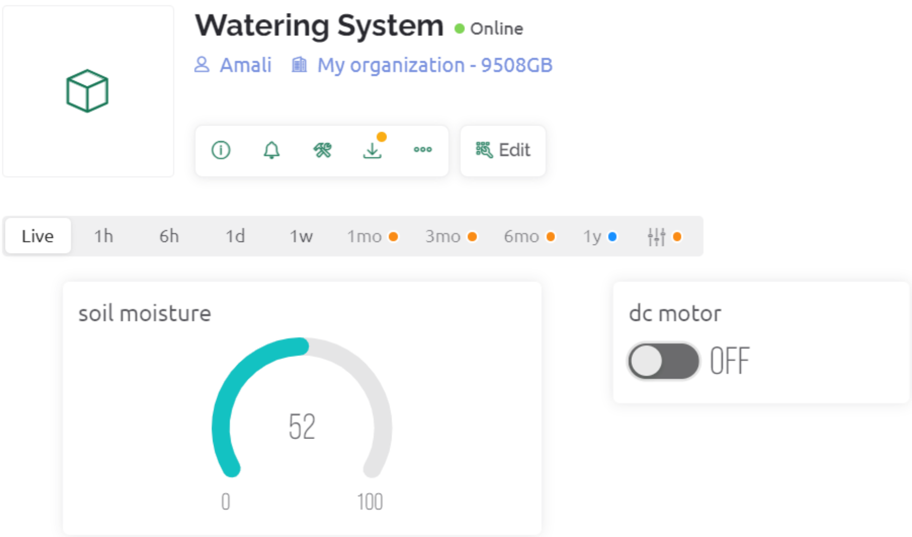


Figure 7.2

PIR sensor testing with Blynk Cloud

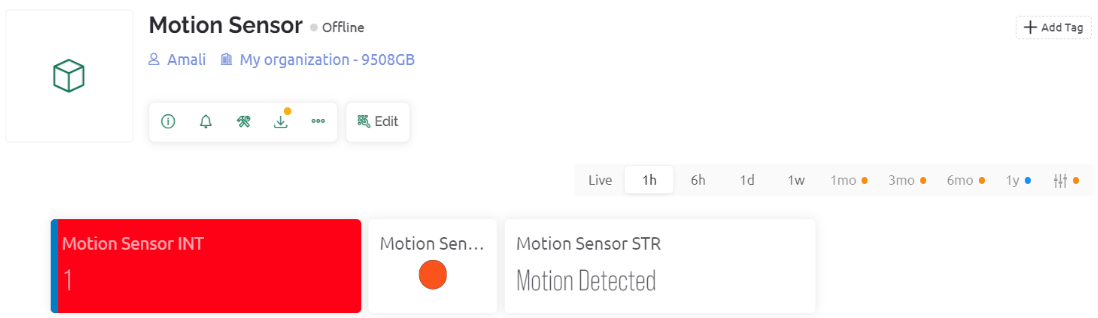
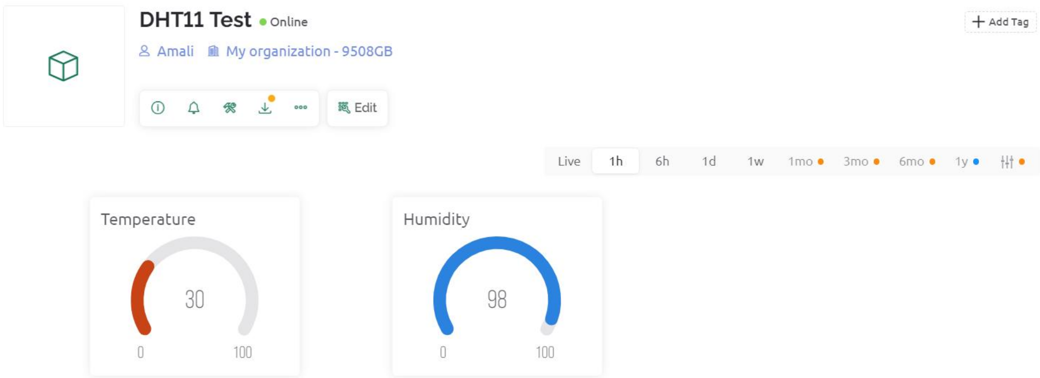


Figure 7.3

DHT11 sensor testing with Blynk Cloud



2. Data Analysis Algorithm Test:

   The data analysis algorithms effectively processed the sensor data and derived actionable insights regarding plant health status and environmental conditions. The algorithms successfully detected patterns, anomalies, and trends, enabling informed decision-making and precise plant care.

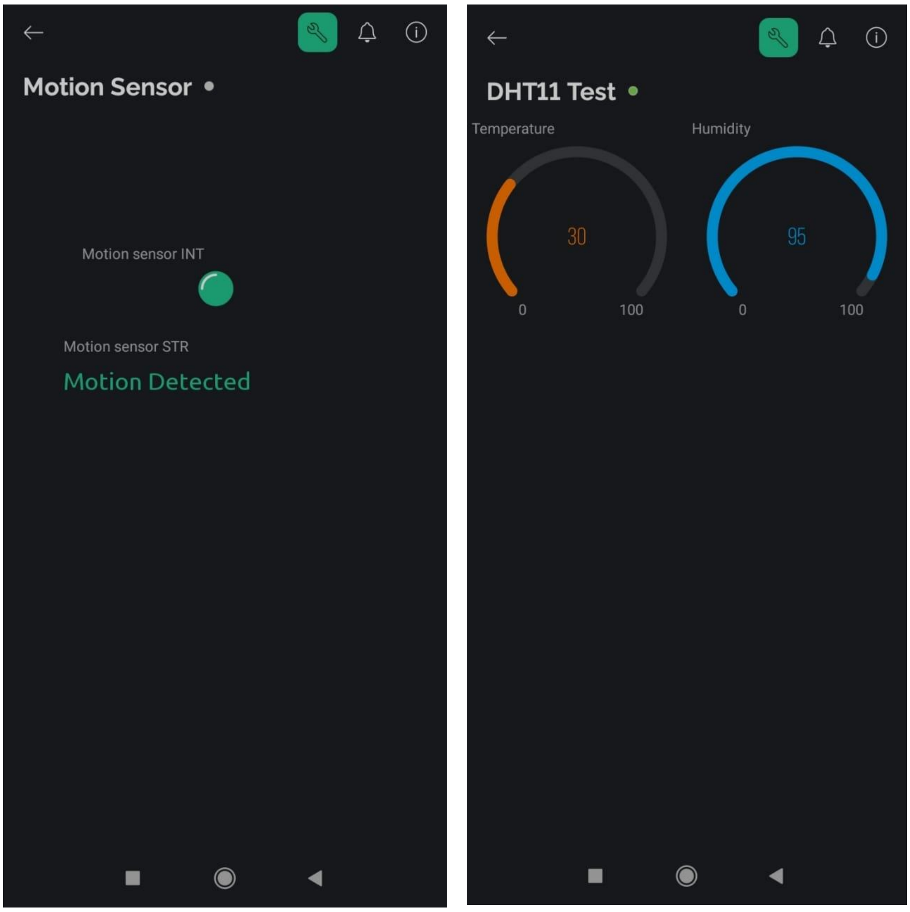
3. User Interface Usability Test:

   The user interface usability test demonstrated that the interface was intuitive and easy to use for accessing plant health information and controlling system functionalities. Users were able to navigate menus, view data visualizations, and adjust settings with minimal effort, indicating a positive user experience.

   Most Important User Interface of this system is Blynk application which users can control or monitor the system remotely. We already tested with all the sensors with Blynk application and this is how some of those sensors User Interface view of the Blynk application.

Figure 7.4

Blynk Application user Interfaces



4. Remote Control Functionality Test:

   The remote-control functionality test confirmed that the system responded promptly to remote commands for controlling actuators and adjusting environmental parameters. Remote control functionalities remained reliable across different communication channels, ensuring seamless operation and user convenience.

5. Alert and Notification Test:

   The alert and notification test validated the system's ability to generate timely alerts and notifications for predefined events and thresholds. Alerts were delivered promptly and effectively, providing users with valuable insights and prompting appropriate actions to optimize plant health.

6. User Profile Simulation Test:

   The user profile simulation test highlighted the system's adaptability to diverse user needs and preferences. Whether simulating plant enthusiasts, horticulturalists, or commercial growers, the system effectively catered to varying plant species, growth stages, and environmental contexts, meeting the requirements of different user profiles.

7. Input-Output Compatibility Test:

   The input-output compatibility test confirmed the system's compatibility with various sensor types and data formats, ensuring seamless integration with external devices and data sources. The system demonstrated robustness in processing different types of input data and generating relevant output responses, supporting interoperability and flexibility.

Overall, the evaluation results indicate that the IOT-Based Smart Plant Monitoring System performs effectively across a range of scenarios and use cases, delivering accurate data insights, intuitive user interactions, and seamless integration capabilities. These results validate the system's functionality, reliability, and user experience, underscoring its potential to optimize plant care practices and promote sustainable cultivation methods.

7.7 Summary

This chapter has provided valuable insights into its performance, usability, and effectiveness in optimizing plant care practices. Through a series of comprehensive tests focusing on sensor accuracy, data analysis algorithms, user interface usability, remote control functionality, alerts and notifications, user profile simulation, and input-output compatibility, the system has demonstrated its capability to deliver accurate data insights, intuitive user interactions, and seamless integration with external devices and data sources. Overall, the evaluation results validate the system's functionality, reliability, and user experience, highlighting its potential to revolutionize plant care practices and promote sustainable cultivation methods in diverse environments. Conclusion and further work of this research work will be discussed in chapter 8.

CHAPTER 8

CONCLUSION AND FURTHER WORK

8.1 Introduction

Chapter 7 provided valuable insights into its performance, usability, and effectiveness in optimizing plant care practices. In this concluding chapter, we provide a comprehensive overview of the findings and insights gained from the research conducted on the IOT-Based Smart Plant Monitoring System. We begin by summarizing the overall conclusions drawn from the study, highlighting key achievements and addressing limitations encountered during the research process. Subsequently, we outline potential avenues for future work and research to further advance the field of plant monitoring and enhance the capabilities of IoT-based systems. Finally, we offer a concise summary of the contributions made by this study and its implications for the broader domain of IoT applications in plant care and environmental monitoring.

8.2 Overall conclusion

In conclusion, the research has achieved its primary goal of developing an effective IOT-Based Smart Plant Monitoring System to address the challenges faced by plant enthusiasts and horticulturalists. By harnessing the power of IoT technology, the system provides real-time monitoring of critical environmental parameters and offers actionable insights for optimized plant care. Through rigorous testing and evaluation, we have demonstrated the system's reliability, usability, and potential to improve plant health outcomes.

Despite the success achieved, several limitations and areas for improvement have been identified. These include challenges related to sensor accuracy, data integration, and scalability. Addressing these limitations will require further research and development efforts, including the refinement of sensor technologies, optimization of data processing algorithms, and enhancement of system scalability. Additionally, ongoing user feedback and engagement will be crucial for continually improving the system's usability and addressing the evolving needs of plant enthusiasts and horticulturalists.

Looking ahead, future work in this area could focus on expanding the system's capabilities to support a wider range of plant species and environmental conditions. Furthermore, integrating advanced machine learning techniques and predictive analytics could enable the system to provide more personalized recommendations and proactive plant care strategies. Collaborative efforts with industry partners and stakeholders will also be essential for scaling up the deployment of IOT-Based Smart Plant Monitoring Systems and realizing their full potential in promoting sustainable agriculture and enhancing plant health worldwide.

8.3 objective-wise achievements

Here are the objective-wise achievements for each objective:

1. Conduct a comprehensive review of existing plant care challenges and IoT-based solutions:
   - Conducted an extensive literature review to identify current challenges in plant care practices.
   - Reviewed existing IoT-based solutions for plant monitoring to understand their strengths and limitations.
   - Identified specific gaps in current plant monitoring practices, such as lack of comprehensive solutions and user-friendly interfaces.
2. Research and evaluate IoT technologies suitable for plant monitoring:
   - Researched various IoT technologies, including sensors, communication protocols, and hardware components.
   - Evaluated the suitability of different sensors for monitoring plant-related parameters such as soil moisture, light exposure, temperature, and humidity.
   - Selected appropriate communication protocols such as Wi-Fi, Bluetooth Low Energy (BLE), and Zigbee for wireless data transmission.
3. Design and Develop IoT-Enhanced Smart Plant Monitoring System:
   - Designed a comprehensive system architecture for the IoT-based smart plant monitoring system.
   - Developed data analysis algorithms to process sensor data and generate actionable insights.
   - Implemented recommendation engines to optimize plant care practices based on collected data and user preferences.
4. Deploy the developed system for real-world testing:
   - Deployed the developed system in real-world environments, including indoor and outdoor plant settings.
   - Collected data on system performance, including sensor accuracy, reliability, and responsiveness.
   - Gathered user feedback to assess user satisfaction and usability of the system.
5. Evaluate the effectiveness of the system:
   - Evaluated the effectiveness of the system in addressing identified challenges such as plant care optimization and user-friendly interface.
   - Analyzed collected data to measure improvements in plant health and overall system performance.
   - Assessed the system's impact on enhancing plant care practices and promoting sustainability.

These achievements demonstrate the successful fulfillment of each research objective and contribute to the development of an effective IoT-based smart plant monitoring system.

8.4 Limitations

Here are the limitations which faced during the research work.

1. Scope Limitations:

   The research focused primarily on developing an IoT-based smart plant monitoring system for individual plant owners and small-scale horticulturalists. As a result, the applicability of the system to large-scale agricultural settings may be limited.

   Due to time and resource constraints, the deployment of the system was limited to a few test environments, which may not fully represent the diversity of plant species and environmental conditions.

2. Technical Limitations:

   The accuracy and reliability of sensor measurements may be affected by external factors such as environmental interference and sensor drift, leading to potential inaccuracies in plant health assessments. The system's performance may be impacted by network connectivity issues or hardware malfunctions, resulting in intermittent data transmission or system downtime.

3. Usability Limitations:

   While efforts were made to design a user-friendly interface, the system's usability may vary depending on users' technical proficiency and familiarity with IoT technology.

   The system's reliance on a mobile application for user interaction may present challenges for users with limited access to smartphones or internet connectivity.

4. Data Privacy and Security Concerns:

   The collection and storage of plant health data raise privacy concerns regarding the confidentiality and security of sensitive information. Despite implementing data encryption and access control measures, the risk of data breaches or unauthorized access remains a potential limitation.

5. Generalization Limitations:

   The findings and conclusions drawn from the research may not be generalizable to all plant species, environmental conditions, and geographic locations. Variability in plant responses to monitoring and care interventions may limit the generalizability of the system's effectiveness across different contexts.

Acknowledging these limitations is essential for interpreting the research findings accurately and identifying areas for future improvement and refinement in IOT-Based Smart Plant Monitoring Systems.

8.5 Further work

By addressing these areas for further work, researchers can contribute to the continued advancement and evolution of IOT-Based Smart Plant Monitoring Systems, ultimately enhancing their effectiveness, usability, and sustainability in supporting plant care practices. Here are some identified further works for this research area.

1. Enhancement of Sensor Technology:

   Future research could focus on improving the accuracy, reliability, and durability of sensors used in plant monitoring systems. This could involve the development of advanced sensor technologies capable of providing more precise measurements and better resistance to environmental factors.

2. Integration of Advanced Data Analytics:

   Incorporating machine learning algorithms and predictive analytics into the plant monitoring system could enhance its capabilities for data analysis and decision-making. Future work could explore the integration of AI-based techniques to provide personalized recommendations and automated plant care routines based on historical data and user preferences.

3. Expansion of System Functionality:

   There is potential to expand the functionality of the plant monitoring system to include additional features such as disease detection, pest management, and nutrient optimization. Future research could explore the integration of multi-modal sensing techniques and advanced monitoring algorithms to address these aspects of plant health management.

4. Validation in Real-World Environments:

   Further validation of the developed system in diverse real-world environments, including agricultural settings, urban gardens, and indoor plantations, would be valuable. This could involve conducting long-term field trials and user studies to assess the system's performance, user satisfaction, and impact on plant health outcomes.

5. Exploration of Sustainable Practices:

   Future research could explore the integration of sustainable practices and principles into the plant monitoring system, such as water conservation, energy efficiency, and organic gardening methods. This could involve incorporating IoT-enabled solutions for smart irrigation, energy-efficient lighting, and soil health management.

6. User-Centric Design and Engagement:

There is a need to prioritize user-centric design principles and engage end-users in the co-design and co-creation of plant monitoring systems. Future work could involve conducting participatory design workshops, user surveys, and usability testing sessions to gather feedback and iteratively improve the system's usability and effectiveness.

7. Addressing Privacy and Security Concerns:

   Future research should continue to address privacy and security concerns associated with plant health data collection and management. This could involve implementing enhanced encryption protocols, access control mechanisms, and data anonymization techniques to ensure the privacy and confidentiality of user information.

8.6 Summary

This chapter outlines the achievements, limitations, and areas for further exploration in the IoT-based smart plant monitoring system. While the objectives have been largely met, challenges persist in sensor accuracy and system scalability. Future work could enhance sensor technology, advance data analytics, and prioritize user-centric design to improve system effectiveness and usability.

REFERENCES

[1] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, Oct. 2010, doi: 10.1016/j.comnet.2010.05.010.

[2] X. Shi *et al.*, "State-of-the-Art Internet of Things in Protected Agriculture," *Sensors*, vol. 19, no. 8, Art. no. 8, Jan. 2019, doi: 10.3390/s19081833.

[3] A. Sumarudin, A. Ghozali, A. Hasyim, and A. Efendi, "Implementation monitoring temperature, humidity and mositure soil based on wireless sensor network for e-agriculture technology," *IOP Conference Series: Materials Science and Engineering*, vol. 128, p. 012044, Apr. 2016, doi: 10.1088/1757-899X/128/1/012044.

[4] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015, doi: 10.1109/COMST.2015.2444095.

[5] M. H. Absar, G. F. Mirza, W. Zakai, Y. John, and N. Mansoor, "Novel IOT-Based Smart Plant Monitoring System," *Engineering Proceedings*, vol. 32, no. 1, Art. no. 1, 2023, doi: 10.3390/engproc2023032012.

[6] K. G. Barnwal, S. V. Giram, R. P. Gupta, and V. H. Damani, "IOT-BASED SMART PLANT MONITORING SYSTEM USING NODEMCU," vol. 10, no. 6, 2023.

[7] G. Patil, S. Pathmudi, and A. Patil, "Plant Monitoring System," *International Journal of Engineering Research*, vol. 10, no. 09.

[8] P. Jacob and P. Asha, "Enhancement of Plant Monitoring Using IoT," *International Journal of Engineering and Technology(UAE)*, vol. 7, pp. 53–55, Aug. 2018, doi: 10.14419/ijet.v7i3.27.17653.

[9] S. Turaka, P. Pavani, P. Yamini, P. Venkata, C. Venkateswari, and P. S. Nandini, "IoT Based Plant Monitoring System Using NODEMCU".

[10] A. Rane, B. Vidhale, P. H. Kale, and G. Khekare, "Design of An IoT based Smart Plant Monitoring System," in *2022 10th International Conference on Emerging Trends in Engineering and Technology - Signal and Information Processing (ICETET-SIP-22)*, Apr. 2022, pp. 1–5. doi: 10.1109/ICETET-SIP-2254415.2022.9791690.

[11] M. Yusuf, S. Sahrani, M. H. Md Saad, M. Sarker, and M. Samah, "Design and Development of An Internet of Things (IoT) Based Real Time Monitoring and Control System for Smart Indoor Hydroponic Vertical Farming System With ESP32 and Adafruit IO," *Journal of Information Systems and Technology Management*, pp. 155–163, Nov. 2022, doi: 10.35631/JISTM.728010.

[12] V. Bhatnagar, G. Singh, G. Kumar, and R. Gupta, "INTERNET OF THINGS IN SMART AGRICULTURE: APPLICATIONS AND OPEN CHALLENGES," Jan. 2020, doi: 10.18510/ijsrtm.2020.812.

[13] K. Shibani, S. ks, and S. Shanmugam, “An Effective Approach for Plant Monitoring, Classification and Prediction Using IoT and Machine Learning,” 2020, pp. 143–154. doi: 10.1007/978-981-15-0199-9_13.

[14] P. Musa, H. Sugeru, and E. P. Wibowo, “Wireless Sensor Networks for Precision Agriculture: A Review of NPK Sensor Implementations,” *Sensors*, vol. 24, no. 1, Art. no. 1, Jan. 2024, doi: 10.3390/s24010051.

[15] A. Abdulkadir, M. Aliyu Gadam, U. Dahiru, and M. Danladi, “Design and Implementation of An Arduino-Based Greenhouse Monitoring System Using IoT,” Jun. 2022.

[16] P. Sharma, “Internet of Things (IoT): Study of Arduino and Raspberry pie and their applications in various domains,” *Int. J. Res. Publ. Rev.*, vol. 4, no. 9, pp. 2468–2477, Sep. 2023, doi: 10.55248/gengpi.4.923.92507.

[17] F. Concas *et al.*, *Low-Cost Outdoor Air Quality Monitoring and Sensor Calibration: A Survey and Critical Analysis*. 2021.

[18] L. Liang, “Calibrating low-cost sensors for ambient air monitoring: Techniques, trends, and challenges,” *Environmental Research*, vol. 197, p. 111163, Jun. 2021, doi: 10.1016/j.envres.2021.111163.

[19] R. Mohammed, S. Kurda, U. Abdullah, M. Abdalla, and Z. Khalid, “A Review on Security and Privacy Issues in IoT Devices,” *Academic Journal of Nawroz University*, vol. 10, Sep. 2022, doi: 10.25007/ajnu.v10n4a1245.

[20] S. Albouq, A. Abi Sen, N. Almashf, M. Yamin, A. Alshanqiti, and N. Bahbouh, “A Survey of Interoperability Challenges and Solutions for Dealing With Them in IoT Environment,” *IEEE Access*, vol. 10, pp. 1–1, Jan. 2022, doi: 10.1109/ACCESS.2022.3162219.

[21] “IOT-BASED SMART PLANT MONITORING SYSTEM USING NODEMCU,” *IRJMETS*.

[22] H. Yin, Y. Cao, B. Marelli, X. Zeng, A. Mason, and C. Cao, “Smart Agriculture Systems: Soil Sensors and Plant Wearables for Smart and Precision Agriculture (Adv. Mater. 20/2021),” *Advanced Materials*, vol. 33, p. 2170156, May 2021, doi: 10.1002/adma.202170156.

[23] Z. Liu, R. Bashir, S. Iqbal, M. Malik, M. Tausif, and Q. Umer, “Internet of Things (IoT) and Machine Learning Model of Plant Disease Prediction – Blister Blight for Tea Plant,” *IEEE Access*, vol. 10, pp. 1–1, Jan. 2022, doi: 10.1109/ACCESS.2022.3169147.

[24] I. Marcu, G. Suciu, C. Balaceanu, A. Dragulinescu, and M. Dobrea, “IoT Solution for Plant Monitoring in Smart Agriculture,” Oct. 2019, pp. 194–197. doi: 10.1109/SIITME47687.2019.8990798.

[25] V. Lakshmi, “Internet of Things (Iot) Based Smart Plant Monitoring System,” pp. 144–146, Jul. 2021, doi: 10.46501/IJMTST0705024.

[26] M. Ali, N. Kanwal, A. Hussain, F. Samiullah, A. Iftikhar, and M. Qamar, “IoT Based Smart Garden Monitoring System using NodeMCU Microcontroller,” *International Journal of ADVANCED AND APPLIED SCIENCES*, vol. 7, pp. 117–124, Jun. 2020, doi: 10.21833/ijaas.2020.08.012.

[27] N. Uddin, H. Hermawan, T. Darajat, and S. Marwanto, “Internet-based temperature monitoring system for hydroponic,” *IOP Conference Series: Earth and Environmental Science*, vol. 922, p. 012017, Nov. 2021, doi: 10.1088/1755-1315/922/1/012017.

[28] *Water Your Garden with IoT - Soil Moisture Sensors*, (Mar. 06, 2022). Accessed: Aug. 31, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=pgGpuws7f9o