IoT Based Smart Indoor Farming

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Certificate

This is certified that the work presented in this project thesis on **“IOT Based Sustainable Indoor Farming”** is entirely written by the following students themselves under the supervision of **Engr. Abdul raziq** & Co-Supervisor: **Engr. Noor ahmed.**

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This project is submitted in partial fulfillment of the requirement for the award of“Degree of Bachelor of Engineering” in Computer Engineering discipline.

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IoT Based Smart Indoor Farming

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	**SDG 9** ☑	**Industry, Innovation, and Infrastructure**
SDG 2 ☑	**Zero Hunger**	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	**SDG 12** ☑	**Responsible Consumption and Production**
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

		Range of Complex Problem Solving	
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	**Depth of analysis required**	**Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.**	
3	**Depth of knowledge required**	**Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.**	
4	**Familiarity of issues**	**Involve infrequently encountered issues**	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	
		Range of Complex Problem Activities	
	Attribute	**Complex Activities**	

1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

ABSTRACT

The project, titled "IoT-Based Smart Indoor Farming," addresses critical industrial and societal challenges related to agriculture, specifically focusing on sustainable indoor farming practices. In recent years, natural disasters, such as floods in Balochistan, have adversely affected crop production, emphasizing the urgent need for innovative solutions to safeguard food security. This project employs Internet of Things (IoT) technologies, utilizing the ESP32 microcontroller along with an array of sensors and actuators, to create an intelligent and adaptive environment for plant cultivation. The system ensures efficient resource usage, optimal growth conditions, and reduced environmental impact, contributing significantly to Sustainable Development Goals (SDGs) related to zero hunger, industry innovation, and responsible consumption and production (SDG 2, 9, and 12). Following the System Development Life Cycle (SDLC), the methodology ensures a systematic approach from planning, implementation, to analysis. Results demonstrate the successful implementation of IoT in creating a scalable and efficient solution for sustainable indoor farming, with the conclusion reflecting on key findings and outlining future directions for research and development in smart farming practices.

Undertaking

It is to certify that this is the original copy of our thesis. We have completed all the chapters of this thesis by our own, under the directions of our supervisor, and we are the sole authors of the thesis. We hereby declare that this thesis has not been submitted for any degree elsewhere.

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Primarily, we express our deep gratitude to the Almighty Allah for granting us the courage and opportunity to embark on our Final Year Project in an emerging field of technology. Secondly, we extend our thanks to the lecturers, staff, and technicians for their cooperative efforts, whether indirect or direct, that significantly contributed to the completion of our project. Heartfelt appreciation is extended to all our friends who provided invaluable assistance during the project's execution.

Our sincerest thanks go to our project supervisor, Engr. Abdul Raziq (Lab Engineer), for his unwavering support and guidance throughout our work. In the project's final stages, when we sought his assistance to address certain issues, he offered us valuable suggestions. We are also grateful to our second supervisor, Engr. Noor Ahmed (Lecturer CSE&S), for his support and guidance. Special mention goes to the Project Review and Evaluation Committee (PREC) for their valuable suggestions.

We express our gratitude to our parents, whose sacrifices, boundless efforts, love, and encouragement have been the driving force propelling us to the stage where we stand today.

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List of Acronyms

IOT	Internet Of Things
SDLC	System Development Life Cycle
UV	Ultra Violet
SDG	Sustainable Development Goals
CEP	Complex Engineering Problem
FAO	Food and agriculture organization
VPD	Vapor pressure deficit
Psat	Pressure at Saturation
PFD	Photon flux density
PAR	Photosynthetically active radiation
MCU	Microcontroller Unit
PWM	Pulse-Width Modulation
CFM	Cubic feet per minute
DC	Direct current
IDE	Integrated Development Environment
GPIO	General Purpose Input Output
AC	Alternating Current
ADC	Analog to Digital Convertor
UART	Universal Asynchronous Receiver/Transmitter
DHT	Digital temperature and humidity
ROI	Return on Investment

Chapter 1

INTRODUCTION

CHAPTER No. 1. INTRODUCTION

1.1.Overview

This chapter provides an overview of the thesis, highlighting the key elements that will be discussed in subsequent sections. It serves as an introduction to the project and sets the foundation for the research conducted.

1.2.Background

In recent years, traditional farming methods have faced numerous challenges due to factors such as limited arable land, unpredictable weather conditions, and inefficient resource utilization. These challenges have led to a growing demand for innovative solutions that can optimize crop production while ensuring sustainability and food security. Smart Indoor Farming, leveraging the power of IoT technologies, has emerged as a promising approach to address these challenges and revolutionize agriculture practices. The concept of Smart Indoor Farming involves creating controlled environments for crop cultivation, typically within enclosed structures such as greenhouses or vertical farms. By closely monitoring and controlling environmental factors such as temperature, humidity, lighting, and nutrient delivery, Smart Indoor Farming systems aim to create ideal conditions that promote optimal plant growth throughout the year, independent of external factors[1]

With the rising global population and diminishing arable land, the need for more efficient and sustainable agriculture practices has become increasingly urgent. By employing IoT technologies, farmers can gain greater control over the farming environment, mitigating the adverse effects of climate variability and optimizing resource utilization. Moreover, Smart Indoor Farming offers the potential to enhance crop productivity and quality[2]

The precise control of environmental parameters allows for the creation of tailored growth conditions that maximize yields while minimizing resource wastage. This approach also enables the cultivation of crops that are typically challenging to grow in certain regions or seasons, expanding the variety and availability of fresh produce throughout the year.

Furthermore, Smart Indoor Farming contributes to reducing the reliance on chemical pesticides and fertilizers[2]

By closely monitoring plant health and implementing targeted pest management strategies, farmers can minimize the use of harmful chemicals, thereby improving food safety and reducing environmental pollution. Additionally, the controlled environment mitigates the risk of contamination from external factors, ensuring the production of high-quality and safe food [3]

By leveraging the potential of IoT technologies in agriculture, Smart Indoor Farming presents an opportunity to transform the way we produce food. It offers a sustainable and efficient approach that addresses the challenges faced by traditional farming methods while promoting food security, resource conservation, and environmentally responsible practices[1]

1.3.Problem

Traditional farming methods face numerous challenges that hinder efficient crop production, leading to concerns regarding food security, resource utilization, and environmental impact. One of the primary problems in traditional farming is the lack of control over environmental factors. External influences like weather fluctuations, pests, and diseases can significantly impact crop growth and yield. Traditional farmers struggle to maintain consistent optimal conditions throughout the year, resulting in unpredictable and often suboptimal outcomes.

Conventional farming practices often result in the overuse of resources, such as water and fertilizers, leading to environmental degradation and financial strain on farmers. Inefficient resource utilization, coupled with the reliance on chemical inputs, escalates production costs and impedes sustainability. Natural disasters, including floods, droughts, and extreme weather events, pose significant threats to agricultural productivity, causing substantial crop damage, economic losses, and disruptions in food supply. In countries like Pakistan, vulnerable to such disasters, agricultural challenges are heightened. The agriculture industry in Pakistan grapples with issues like limited arable land, water scarcity, and outdated farming practices, underscoring the critical need for innovative solutions to maximize crop productivity, conserve resources, and ensure food security.

1.4.Objective

- To develop a Smart Indoor Farming system with multiple sensors and actuators to optimize crop production in controlled environments.
- To develop a web dashboard and mobile application for real-time monitoring and control of the indoor environment.
- To implement real-time control, monitoring and automation and smart system in the environment, which can assess the environment condition (Temperature, Humidity, Soil Moisture, Air Quality and Actuators i.e. Water Pump, Grow Lights and Fans).

1.5.Significance of the Study

In recent years, traditional farming methods have faced numerous challenges due to factors such as limited arable land, unpredictable weather conditions, and inefficient resource utilization[3]

The impact of floods on Pakistan's economy is colossal as the economy grew on average at a rate of 2.9 % per year during the last five years. The Pakistan Economic Survey shows that Pakistan lost a total of 5,072 lives and $19 billion to the floods in 2010, 2011, 2012, 2013 and 2014[4]

By incorporating IoT-based technologies, this study aims to address these challenges by improving resource efficiency, enhancing crop yield predictability, and promoting sustainable farming practices in the context of Baluchistan.

1.6.Alignment with Sustainable Development Goals:

The study of Smart Indoor Farming using IoT technologies aligns with several United Nations Sustainable Development Goals (SDGs). It contributes to SDG 2 (Zero Hunger) by increasing food production and accessibility, SDG 9 (Industry, Innovation and Infrastructure) by promoting innovative technologies in agriculture, and SDG 12 (Responsible Consumption and Production) by fostering sustainable farming practices and reducing waste. The findings of this study will highlight the role of Smart Indoor Farming in achieving these global goals.

By examining the significance of implementing a Smart Indoor Farming system using IoT technologies, this study sheds light on the potential benefits and implications for sustainable agriculture. The findings will serve as a valuable resource for policymakers, farmers, and researchers seeking to enhance food production, improve resource efficiency, and foster innovation in the agriculture sector.

1.7.Scope of the Study

- The scope of this study encompasses the implementation and evaluation of a Smart Indoor Farming system using IoT technologies in the context of sustainable agriculture. The study aims to explore the practical implementation of IoT technologies in creating a Smart Indoor Farming system. This includes the installation and integration of sensors, actuators, controllers, and data management systems to monitor and control environmental factors such as temperature, humidity, lighting, and air quality level. The scope also involves the development of a mobile application and web-based dashboard for remote access and data visualization.
- The study focuses on crop cultivation within controlled environments, such as indoor grow rooms or greenhouses. It investigates the effects of environmental control and optimization on crop growth, yield, and quality. The scope includes the selection of suitable crop varieties, monitoring of plant growth parameters, and the evaluation of the Smart Indoor Farming system's impact on crop productivity.
- Efficient resource management is a crucial aspect of sustainable agriculture. The study examines the optimization of resource utilization, including water, energy, and fertilizers, within the Smart Indoor Farming system. It investigates strategies to minimize resource wastage, improve efficiency, and reduce the environmental impact associated with traditional farming practices.
- The study encompasses the collection, analysis, and interpretation of data generated by the Smart Indoor Farming system. It explores the use of data analytics techniques to derive

actionable insights for crop management, resource allocation, and decision-making processes.

1.7.1. Alignment with Sustainable Development Goals (SDGs)

The project aligns with several Sustainable Development Goals, including Goal 2 (Zero Hunger), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 12 (Responsible Consumption and Production). By promoting efficient resource use and technological innovation, the system contributes to broader sustainability objectives.

1.7.2. CEP LEVEL

1. **WP1 Depth of Knowledge:**
    - Achieving a high CEP level in WP1 involves a comprehensive understanding and mastery of the foundational knowledge relevant to the project. This includes proficiency in microcontroller programming, sensor integration, and the intricacies of the ESP8266 microcontroller. A high CEP level in WP1 would indicate a deep understanding of the technical aspects underpinning the project.
2. **WP3 Depth of Analysis:**
    - Attaining a high CEP level in WP3 requires a thorough and insightful analysis of the data collected from the implemented system. This involves not only the ability to interpret sensor data but also to draw meaningful conclusions, identify patterns, and make informed recommendations for system improvements. A high CEP level in WP3 demonstrates a keen analytical capability in interpreting the results of the project.
3. **WP4 Familiarity of Issues:**

- Achieving a high CEP level in WP4 involves a broad and nuanced understanding of the contextual issues surrounding smart indoor farming. This includes familiarity with challenges in sustainable agriculture, economic considerations, and the broader implications of the project in addressing global goals such as sustainable development. A high CEP level in WP4 indicates a deep awareness and comprehension of the broader issues relevant to the project.

1.7.3. Limitations and Delimitations:

The study acknowledges certain limitations and delimitations.

- It recognizes that the implementation of the Smart Indoor Farming system may require initial investment and technical expertise.
- The study focuses on specific crops and does not cover all possible variations in plant species and growth requirements.

Thesis Outline

This section provides an outline of the thesis structure, highlighting the key chapters and their contents:

Chapter 1: Introduction

The first chapter serves as an introduction to the thesis. It provides an overview of the project, presenting the background, problem statement, objectives, research questions, significance of the study, scope, and the thesis outline.

Chapter 2: Literature Review

The second chapter delves into a comprehensive literature review of existing research, studies, and scholarly articles related to Smart Indoor Farming, IoT technologies, and sustainable agriculture. It explores the theoretical foundations, conceptual frameworks, and technological advancements in the field. This chapter establishes a solid knowledge base and theoretical framework for the study.

Chapter 3: Methodology

The third chapter focuses on the methodology employed in the research. It describes the research design, data collection methods, and analysis techniques used to investigate the effectiveness and impact of the Smart Indoor Farming system. This chapter outlines the experimental setup, data collection procedures, and the statistical tools employed for data analysis.

Chapter 4: Implementation and Results

In the fourth chapter, the research findings and data analysis are presented. It includes a detailed analysis of the collected data, evaluation of the Smart Indoor Farming system's performance, and an examination of the impact on crop productivity, resource utilization, and environmental factors. This chapter also includes data visualizations, graphs, and charts to support the analysis.

Chapter 5: Conclusion

The fifth chapter provides a comprehensive discussion of the research findings. It interprets the results in the context of the research objectives, research questions, and existing literature. This chapter highlights the implications of the findings, identifies patterns and trends, and offers insights into the practical applications of the Smart Indoor Farming system. It also addresses any limitations and delves into areas for further research.

References

The thesis includes a list of cited references, providing a comprehensive bibliography of the sources used throughout the research. The references are formatted according to the specified citation style.

Appendices

The appendices section includes additional supporting materials, such as detailed experimental procedures, data collection forms, and supplementary information that enhances the understanding of the research process and findings.

Chapter 2

LITERATURE REVIEW

CHAPTER No. 2. **Literature Review**

2.1.Introduction

By 2050, there will be 8.9 billion people on the planet (United Nations, 2017). Food production must increase at a rate commensurate with the rapid population rise. However, the amount of arable land per person is decreasing (FAO, 2011). Because of this, creative approaches to food production are required in order to feed the world's population while making efficient use of the natural resources and accessible space[1]. According to the United Nations (2017), if the current population momentum continues, the world's population is expected to reach 8.3 billion by 2030 and stabilize at 8.9 billion. The world's yearly agricultural production has to rise by 70% between 2005 and 2050 in order to feed the expanding population (FAO, 2011). A primary cause for such a large increase is due to increased meat consumption and the large volumes of crops needed as feedstock (FAO, 2011). However, as figure 3 illustrates, the amount of arable land per person is declining. By 2050, it is expected to have decreased to less than 0.20 hectares per person, or one-third of the amount in 1970 (FAO, 2011) [5]. A rising industry, protected agriculture is being practiced on all continents of the globe, with an estimated 5.2 million hectares under protection as of 2014 [1]. Greenhouses that are covered either by plastic films in mild climates, or by glass or rigid plastic in temperate and cold climates, extend over an area that averages 4.7 million ha in the temperate regions of Europe, Asia, and America, and over an area that averages 364,000 ha in the Mediterranean, as well as over an area that averages 156,000 ha in the tropical and subtropical regions [6].

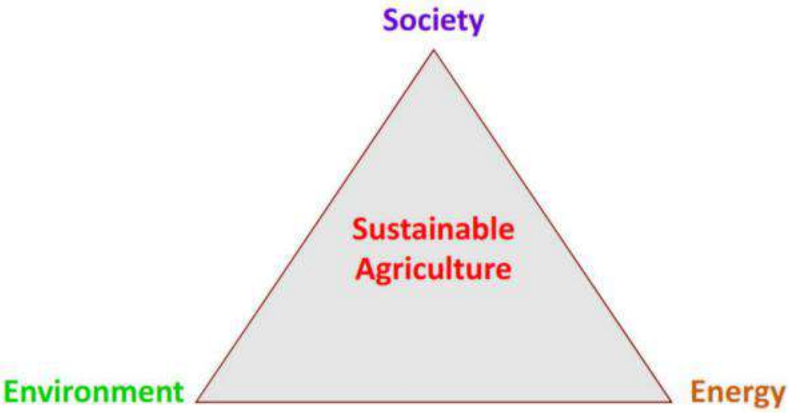


Figure 2.1: Factors of sustainable agriculture.

2.2.Impact of Floods on Pakistan's agriculture and economy

Floods have a massive effect on Pakistan's economy, which over the last five years has grown at an average annual rate of 2.9%. According to the Pakistan Economic Survey, Pakistan suffered losses from floods in 2010, 2011, 2012, 2013, and 2014 totaling $19 billion and 5,072 fatalities. The chart displays the area of crops that were impacted by flooding in Punjab, Sindh, KPK, Baluchistan, Azad Jammu & Kashmir, and Gilgit Baltistan between 2010 and 2014 [4].

Table 2.1: Impact of Floods on Pakistan's agriculture and economy.

Year	**2010**	**2011**	**2012**	**2013**	**2014**
Punjab	0.42	0.00	0.19	0.30	0.98
Sindh	0.30	0.88	0.10	0.10	0.00
KPK	0.05	0.00	0.00	0.00	0.00
Baluchistan	0.05	0.00	0.00	0.00	0.00
AJK	0.01	0.00	0.00	0.00	0.00
GB	0.00	0.00	0.00	0.00	0.00
Total	0.84	0.00	0.47	0.45	0.98

Compared to other industrial sectors, agriculture adopts technology more slowly, and the rate of adoption varies greatly depending on the region and type of agricultural method. In actuality, low productivity arises from the fact that many agricultural operations still rely on human labor and antiquated, low-tech methods. Overall, the existing state of affairs falls well short of Agriculture 4.0's objectives, which are to turn the sector into a data-driven, efficient industry that employs cutting-edge technologies to maximize productivity and advance sustainability[5].

2.3. Challenges in traditional agriculture

The problem facing traditional agriculture is keeping weeds, pests, and diseases from ruining crops and making consumers ill. By cultivating in a controlled environment without soil and working with positive-pressure ventilation to efficiently prevent insect pest contamination, VF can greatly reduce these dangers.[1].

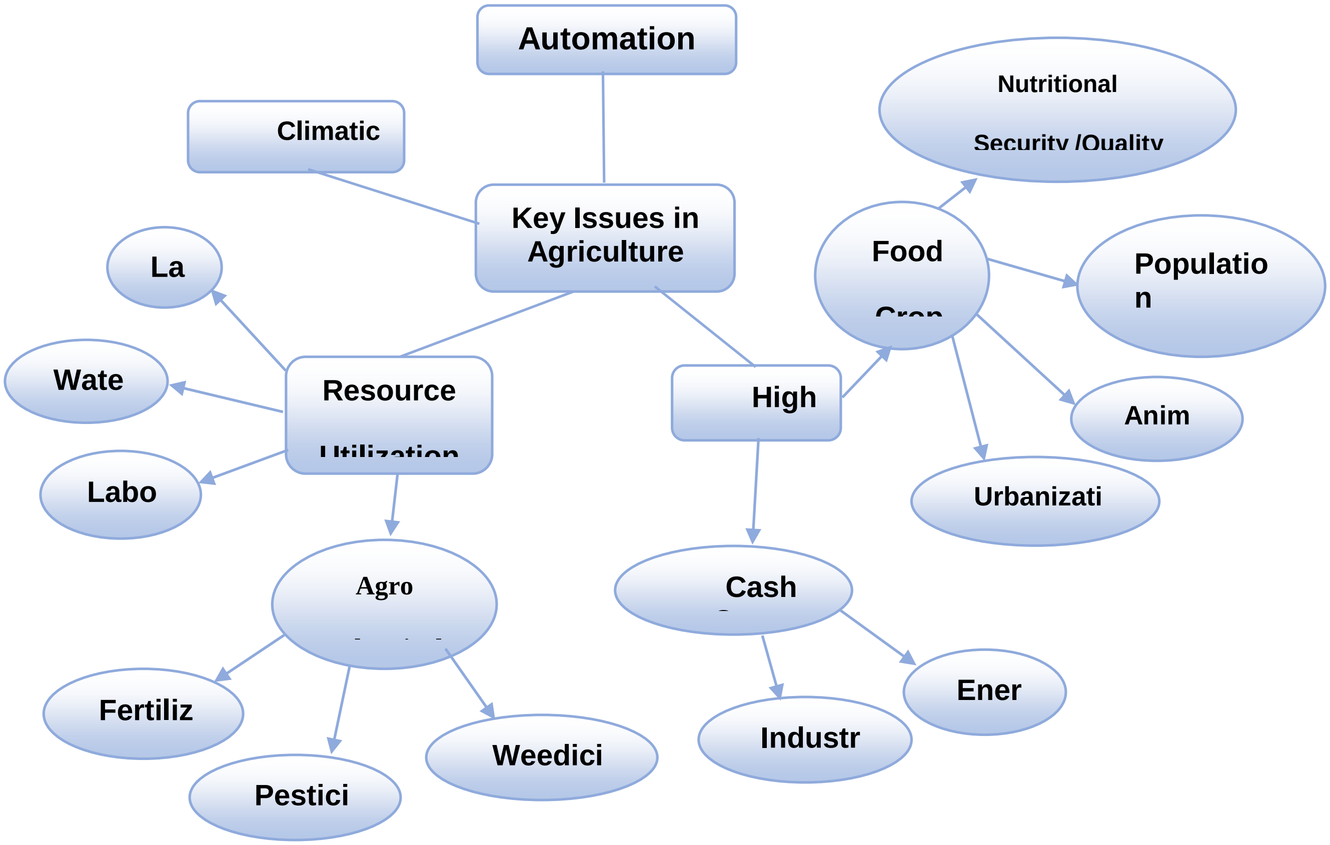


Figure 2.2: Key issues of technology in the agriculture industry.

2.4.Internet of Things

A new technology called the Internet of Things (IoT) enables remote device connections for smart farming [22]. In order to improve efficiency and performance across all sectors, the Internet of Things has started to have an impact on a wide range of industries, including health, trade, communications, energy, and agriculture [23–25]. Applications currently in use offer insights on the impact of IoT and its as-yet-unobserved habits. But as technology advances, it becomes clear that Internet of Things (IoT) technologies play a significant role in many farming activities. These include the use of IoT technologies for data acquisition, data acquisition, smart objects, sensors, mobile devices, cloud-based intelligent information, decision-making, and the automation of agricultural operations (Figure 4).

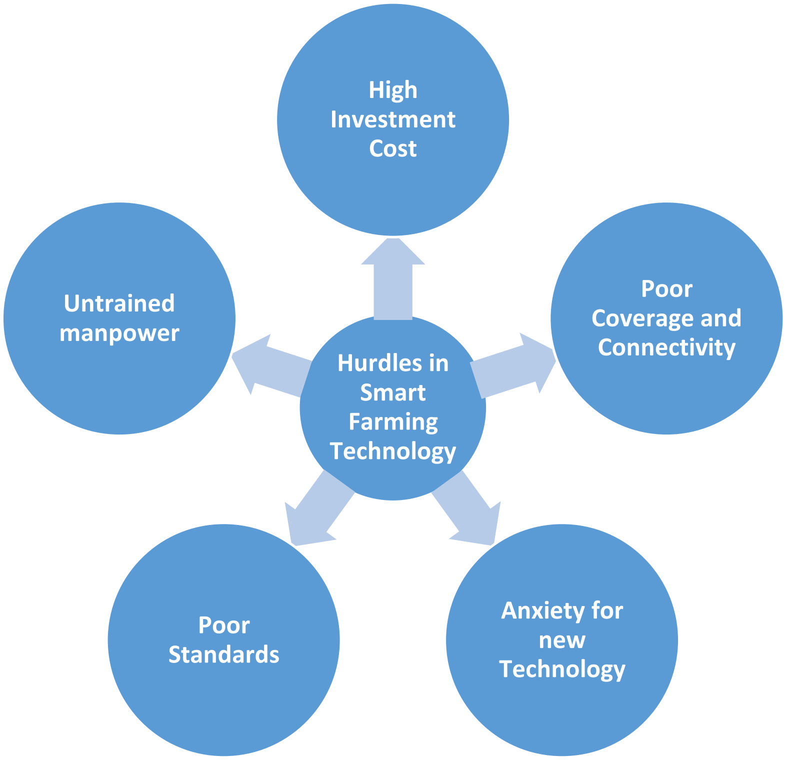


Figure 2.3: Hurdles in Smart Farming Technology

2.5.Required parameters Thresholds

2.5.1. Humidity

The amount of moisture in the air has an impact on the rate of transpiration of plants, which hinders their health, growth, and development. Though technically challenging to achieve, a relative humidity range of 80–90% during the day and 65–75% at night is often advised. [4]. The moisture content, or water content, in the growth chamber is measured by the humidity sensor. This is crucial to the growth of plants. The water from the tank must be supplied if the moisture content of the chamber is less than that of the nutrient + water tank. In the growing chamber, the humidity is kept between 80 and 100 percent[6]. According to research, maintaining the ideal climate for crop growth depends on controlling the relative humidity inside the greenhouse. This is especially true in closed greenhouses, where the water vapor must be removed by condensation or absorption processes to keep the environment healthy. This is thought to be the most difficult climate parameter to regulate. The relative humidity also causes the air inside temperature, as the self-cooling evaporation of the vegetation is dependent on the vapor pressure deficit in the air. According to Amani's research, the ideal relative humidity in a greenhouse should be between 60 and 80% [6]. The study adds here that it is vital to clarify that the appropriate humidity levels for a plant are strongly reliant on the water stresses, extreme weather conditions, the danger of fungus/pest/insect attack, the maturity stage, and the plant growth stage. Therefore, optimal humidity levels are necessary for a plant to grow to its full potential. These levels are expressed as the vapor pressure deficit (VPD), which is the difference between the water vapor pressure at saturation (Psat) and the actual water vapor pressure at the greenhouse's temperature (P).

2.5.2. Temperature

It is always necessary to consider the link between the temperature and humidity. For instance, at 20◦/80% relative humidity, one m3 of air may absorb an additional 3 g of water; at 30◦/80%, this amount is 5.5 g; at 40◦, it is already 11.2 g; at these higher levels, it is significantly more than the saturation point [12]. According to Nelson, the healthy growth of most plants is noticed for temperature range between 10 and 24 ◦C, while the best growth for greenhouse plants is observed for temperatures fluctuating between 15 and 30 ◦C . Nelson discovered that, in sunny conditions, a temperature differential of 8 to 10 ◦C is required for crop growth between day and night. The ideal temperature ranges for different plant species vary. The temperature requirements for a few different greenhouse crops in hot and dry areas are given in Table [6].

2.5.3. Cooling and Heating

It states that the largest percentage of energy usage, between 65 and 85%, is attributed to the cooling and heating processes, which work to maintain the ideal interior atmosphere for crop growth. In the Mediterranean region, cooling energy consumption is around 100,000 kWh/ha annually; however, the literature currently in publication does not provide a numerical estimate for the hot regions.[6].

Table 2.2: Climate requirements for selected greenhouse crops in hot and arid regions.

Optimal T (◦C)			Optimal RH (%)	Optimal DLI (mol m−2 d−1)	References
	Day	Night			
Tomato	23-27	13-16	50-80	15-53	[13-16]
Pepper	22-30	14-16	50-70	20-53	[17-20]
Cucumber	25-30	16-18	70-90	20-53	[16,18,20]
Lettuce	24–28	13-16	60-80	16-40	[16,20,21]
Aubergine	25–28	14–16	50–60	40–55	[16-18,20,22]
Cabbage	15–16	2	70–80	42	[20,23]
Beans	22–26	16–18	70–80	19–24	[18]
Peas	25–30	16–18	70–80	42	[20]
Strawberry	20–26	13–16	50–65	17–20	[24-26]
Melon	32	14–20	65–75	58–64	[16,20,27,28]

2.6.Plant Light requirement

Plants get their energy from light, which they use for growth and development. As a result, it is seen to be a highly important consideration while growing plants indoors. Thus, successful cultivation requires an awareness of plants' light requirements. For the best growth, plants require very specific lighting conditions, which include light source, duration, quality, and intensity. A healthy, high-yielding plant growth can be ensured by comprehending and optimizing these aspects, which will lead to a high-quality finished product. In the photosynthetically active radiation (PAR) area of the spectrum, which is the region employed for photosynthesis, the amount of light received by plants is expressed in terms of photon flux density (PFD) (µmol/m2 s). Depending on the type of plant, its stage of growth, and certain climatic elements like humidity and temperature, different plants require different amounts of light. Generally speaking, growth requires at least 100–200 µmol/m2 of PAR light intensity [3].

2.6.1. Photosynthetically Active Radiation

The part of the light spectrum that plants employ for photosynthesis is known as PAR. The visible light spectrum, or PAR, is made up of wavelengths that range from around 400 nm to 700 nm. The number of photons emitted on a unit area per unit of time, or PFD, is used to measure PAR. Through the process of photosynthesis, plants transform PAR light energy into chemical energy in the form of glucose and other carbohydrates. Generally speaking, vegetative growth requires a minimum PAR intensity of about 100–200 µmol/m2 s, whereas flowering and fruiting require 400–600 µmol/m2 s or more [5]. Plant growth and development under varying intensity values can be monitored and experimented with to identify the ideal PAR intensities for a given plant species and growth stage. [3]

2.6.2. Far Red-Light Effect

The visible spectrum's upper edge, or far-red, has a wavelength range of 700–750 nm. Smaller plants can get this type of light since it can pass through thick canopies. This phenomenon, which is easily witnessed in nature, is how far-red light can encourage stem elongation in these plants and force them to grow towards the light direction in order to get the other wavelengths [3]. Certain plants grown for their stems may benefit from short exposure times and intensities of 5–20 µmol/m2 s of far-red light. However, excessive exposure to far-red light can also cause a decline in leaf size, chlorophyll content, and nutritional value of plants. Consequently, based on the growth stage of the created species, the length of exposure and the intensity of the far-red light should be carefully adjusted to match the ideal intensity needed by the species[3].

2.6.3. Ultraviolet (UV) Light Effect

UV light falls between 100 and 400 nm in the non-visible light spectrum. UV radiation can encourage plants to produce essential chemical substances like flavonoids and alkaloids [27]. Numerous fruits and flowers have distinct hues due to flavonoids, which have also been shown to have positive effects on human health [5].

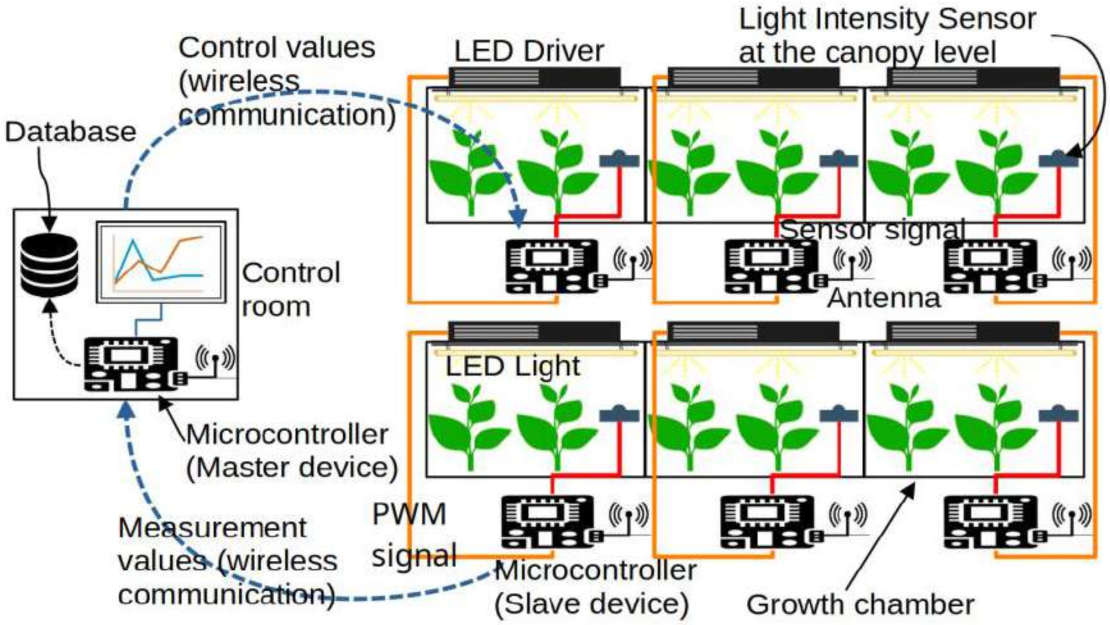


Figure 2.4: Light Control System

2.7.Smart Farming

Historically, the production of food on farmed areas for human survival and animal breeding was associated with old agricultural systems [12], and was known as the first conventional agricultural age. This mostly involved the use of labor and livestock. Shovels and sickles were among the basic implements used in farming. Because manual labor was the primary method of doing business, productivity remained low (Figure 3).

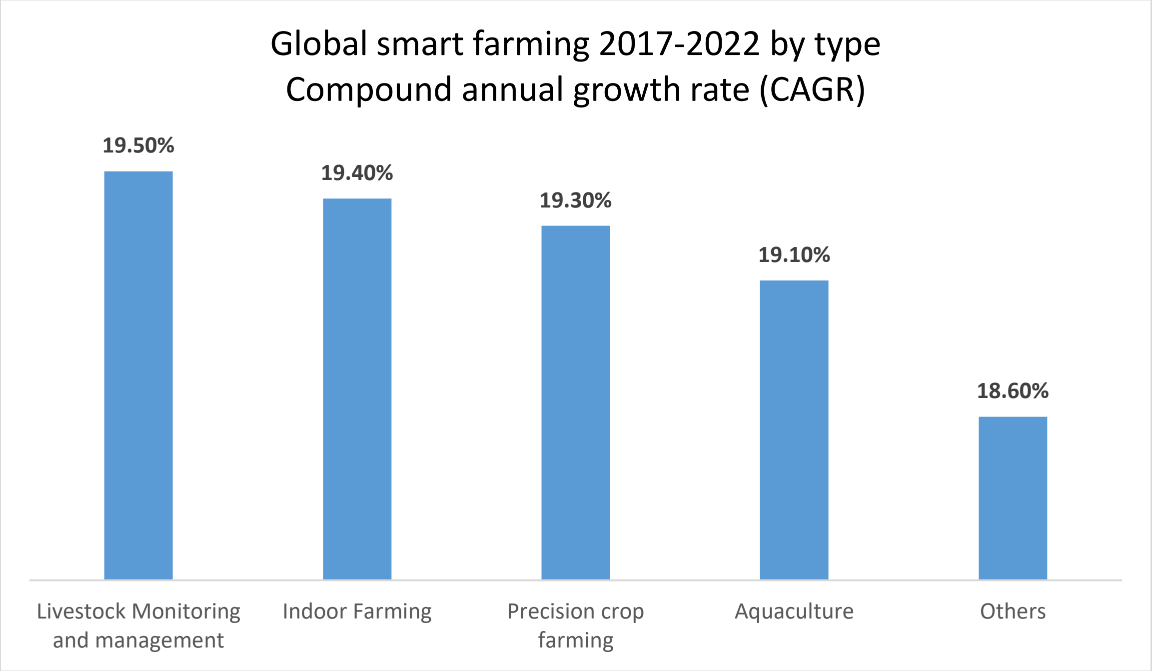


Figure 2.5: Global Smart Farming 2017-2022 (BIS Research)

Chapter 3

METHODOLOGY

CHAPTER No. 3. METHODOLOGY

1. Introduction

The agriculture has revolutionized these years by leveraging different technologies. Reviewing the literature review it is cleared that this technology of growing plants in an indoor environment is being used by industries and locals in different regions of world. The methodology of this project divided into three stages, 1. Planning, 2. Implementation and 3. Analysis. Which are subdivided into two sections each. So, the first step of the project methodology is planning, divided into two parts, 1. data collection, 2. software and hardware requirements of the project. The second step is Implementation which is also divided into two sections 1. Testing Point, 2. Implement the project and the third and final step of the methodology is Analysis which is also divided into two sections 1. Analyze the performance, 2. Identify the conclusion.

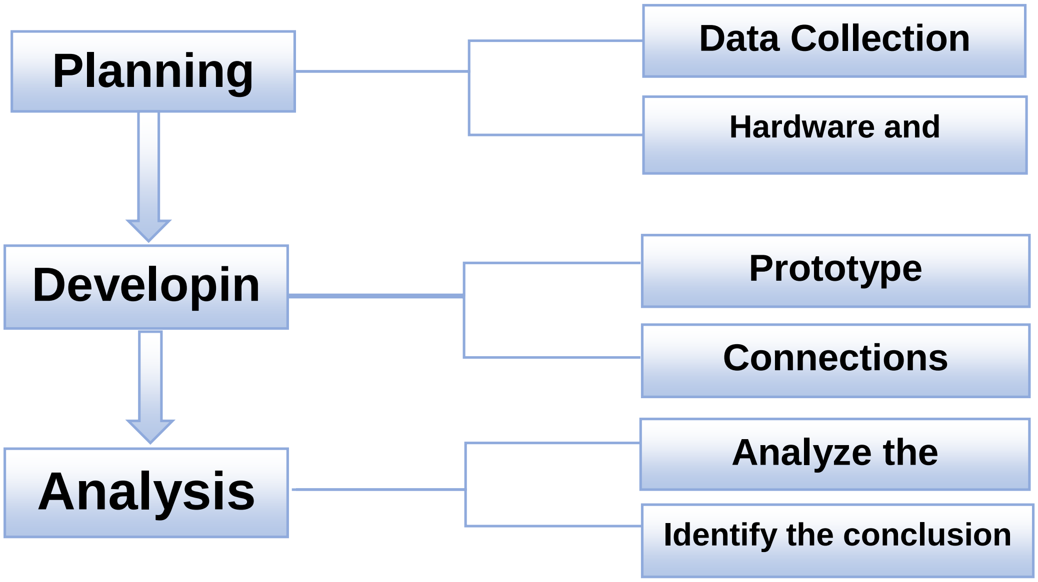


Figure 3.1: System Development Life Cycle (SDLC) Phases of Methodology

Designing the environment where the system works automatically using IoT technologies where user can monitor and also control it from anywhere through internet which is connected with the system of the environment. So, to design this project we need to collect the complete data related to this project which will help us in creating this environment. Also, we have to look for the requirements of the project through the collected data that which hardware components and the software are required to accomplish this project in a good manner.

As we are using Node MCU ESP32 module for this project with the cloud services of Blynk where we use multiple sensors and actuators for this purpose. The sensors are DHT11, Soil Moisture Sensor, Air Quality sensor and Grow Lights with the to detect the light and also the actuator for irrigation purposes. For this we have to go through all of these in detail to collect all data and know about these to use in our project.

3.1.1. Identifying All Information

The planning phase is a critical step in the System Development Life Cycle (SDLC), where the foundation for the entire project is laid. The project, titled "IoT-Based Sustainable Indoor Farming," aims to create an automated system for indoor cultivation that ensures optimal conditions for plant growth and resource utilization. The key aspects identified during the planning phase include the following.

3.1.2. Data Collection

Climate control processes in the Indoor farming by means of manual and smart control systems are investigated first. Subsequently, the different cooling technologies that provide the required ranges of temperature and humidity inside the Indoor farming environment are detailed. Protected agriculture is a growing activity that is spreading throughout all the world continents, and that covers an area that was estimated to be 5.2 million ha in 2014 [1]. Greenhouses that are covered either by plastic films in mild climates, or by glass or rigid plastic in temperate and cold climates, extend over an area that averages 4.7 million ha in the temperate regions of Europe, Asia, and America, and over an area that averages 364,000 ha in the Mediterranean, as well as over an area that averages 156,000 ha in the tropical and subtropical regions.

1. *a. Plant Growth Requirements*

The following are the specific environmental parameters, such as temperature, humidity, light intensity, soil moisture, and air quality, necessary for the healthy growth of the chosen plant species.

Table 3.1: Different Plants Growth Requirement Thresholds.

Optimal T (◦C)			**Optimal RH (%)**	**Optimal DLI (mol m−2 d−1)**	**References**
	Day	**Night**			
Tomato	23-27	13-16	50-80	15-53	[13-16]
Pepper	22-30	14-16	50-70	20-53	[17-20]
Cucumber	25-30	16-18	70-90	20-53	[16,18,20]
Lettuce	24–28	13-16	60-80	16-40	[16,20,21]
Aubergine	25–28	14–16	50–60	40–55	[16-18,20,22]
Cabbage	15–16	2	70–80	42	[20,23]
Beans	22–26	16–18	70–80	19–24	[18]
Peas	25–30	16–18	70–80	42	[20]
Strawberry	20–26	13–16	50–65	17–20	[24-26]
Melon	32	14–20	65–75	58–64	[16,20,27,28]

- Research the optimal ranges for each environmental parameter to ensure the plants receive the ideal conditions for photosynthesis and proper nutrient uptake.

2. *b. Functional Requirements:*

a. Sensors**:**

- DHT11 for temperature and humidity monitoring.
- Soil moisture sensor for soil moisture level detection.
- Air quality sensor for monitoring the indoor air environment.
- for detecting ambient light conditions.

b. Actuators:

- Watering system controlled by the microcontroller.
- Grow lights for photosynthesis controlled based on light conditions.
- Exhaust fans for temperature and humidity control.

c. Communication:

- ESP32 connected to Blynk cloud for data storage and real-time monitoring.

3.1.3. System Overview:

a. *Objective:* To design and implement an IoT-based solution for sustainable indoor farming.

b. *Components***:** ESP32 microcontroller, various sensors (DHT11, soil moisture, air quality, PIR motion), actuators (watering system, grow lights, exhaust fans), relays for device control.

c. *Communication***:** ESP32 connected to the Blynk cloud for real-time monitoring.

3.1.4. Data Flow:

a. Sensors collect environmental data.

b. Data is processed by the ESP32 microcontroller.

c. Processed data is sent to the Blynk cloud for storage and monitoring.

3.1.5. Requirements (Software and Hardware)

3.1.5.1. Sensors

- Understand the specifications and operating principles of the sensors employed in the system, including the DHT11 temperature and humidity sensor, soil moisture sensor, and air quality sensor.

- **DHT11 (Temperature and humidity) Sensor**: Measures temperature and humidity for ideal plant growth conditions.

- **Temperature range**: 0°C to 50°C (+/- 2°C **accuracy**)
- **Humidity range**: 20% to 80% RH (+/- 5% RH **accuracy**)

Figure 3.2: DHT11 Sensor

This sensor provides basic temperature and humidity readings within a comfortable range for most plants. Its accuracy is decent, but you can consider calibrating it for higher precision.

- **Soil Moisture Sensor**: Measures temperature and humidity for ideal plant growth conditions.

- **Moisture range**: 0% to 100% (varies depending on sensor model and calibration)

- **Accuracy**: +/- 5% to 10% (depending on sensor model and soil type)

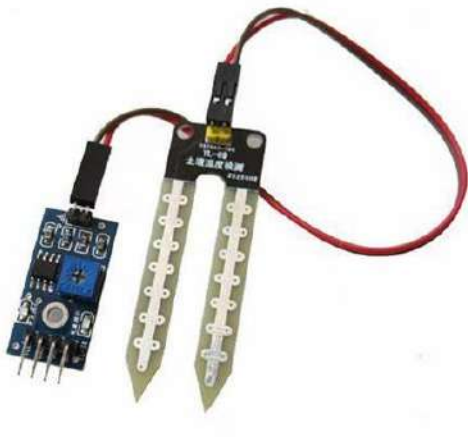


Figure 3.3: Soil Moisture Sensor

This sensor helps prevent overwatering or under watering. However, its accuracy can be affected by soil type and calibration. Consider using a sensor specific to your chosen growing medium for better accuracy.

- **Air Quality Sensor (MQ135):** Monitors harmful gases and CO2 levels for healthy plant respiration.

- **CO2 range**: 0 to 2000 ppm (typical range for indoor environments)
- **Accuracy**: +/- 3% to 5% (depending on sensor model and calibration)

Figure 3.3: MQ135 Air Quality Sensor

Monitoring CO2 levels is crucial for plant respiration and growth. This sensor's accuracy is sufficient for most applications, but you can research specific models for higher precision if needed.

3.1.5.2. *Actuator Functionalities*

- **Watering Pump**: Automatically delivers water to plants based on soil moisture needs.
- **Flow Rate**: 80 ~ 120 L/H,
  - **Maximum Lift**: 40 ~ 110 mm
  - **Operating Voltage**: 6 ~ 9V
- Typically, 2-8 liters per minute (check your specific model)
- **Control**: Usually via an on/off relay or pulse-width modulation (PWM) signal

Figure 3.4: DC 12v Water Pump

The flow rate determines how quickly water is delivered. PWM allows finer control over water delivery duration. Choose a pump suitable for your pot size and watering needs.

- **Grow Lights**: Provide artificial light for photosynthesis in controlled environments.
- **Spectrum**: Different types emit specific wavelengths for optimal plant growth (e.g., red and blue for photosynthesis)
- **Intensity**: Measured in watts or lumens (adjust based on plant light requirements)
- **Control**: Usually via an on/off relay or PWM signal for dimming

Figure 3.5: Grow Light for Plants

Select lights tailored to your plant species and life stage. Adjust intensity based on light sensors or environmental data for efficient growth.

- **Exhaust Fans 12v**: Regulate temperature and humidity by removing excess heat and moisture.
- **Rated Speed**: 6,300 min-1
- **Max. Airflow**: 2.55 m3/min [90 CFM]
- **Max. Static Pressure**: 211 Pa [0.847 inchH2O]
- **Operating Temperature**: -20 to +70 °C

Figure 3.6: Exhaust fan (DC 12v)

- **Power Adapter 12V:** Supply reliable power for electronic devices with efficiency and stability.
- **Rated Output Voltage:** 12V DC
- **Max. Output Current**: [2A]
- **Input Voltage Range**: [100-240V AC]
- **Operating Temperature**: -10 to +40 °C

Figure 3.7: DC (12v 1.5A) Power Adapter

- Specify the control mechanisms for each actuator, such as relay controls, to enable precise regulation of environmental parameters.

Relays:

- **Purpose:** Controls the operation of actuators based on microcontroller instructions.

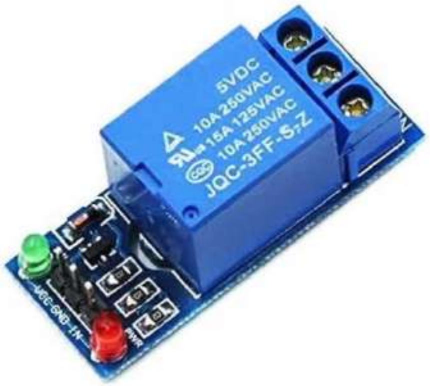


Figure 3.8: Relay Module (DIGITAL SWITCH)

ESP32 Microcontroller

The ESP32 is the brain of your indoor farming operation, so let's delve deeper into its capabilities:

Figure 3.9: ESP32 Microcontroller

1. Processing Power:

- **CPU**: Ten silica Xtensa LX106 32-bit RISC processor

- **Clock Speed**: 80 MHz or 160 MHz (depending on model)

This CPU packs enough punch to handle your project's needs. It can process sensor data, control actuators, communicate with Blynk, and manage multiple tasks simultaneously. The 160 MHz option offers even faster processing for complex algorithms or data analysis

2. Memory Capacity:

- **Flash Memory**: Up to 4 MB (depending on model) for storing code and data
- **SRAM**: 32 KB instruction RAM, 32 KB instruction cache RAM, 80 KB user data RAM

This memory space allows you to store your code, sensor readings, and other variables comfortably. You can even choose a model with more flash memory if you plan on implementing more advanced features or AI models in the future.

3. **Communication Interfaces**:

- **Wi-Fi**: IEEE 802.11 b/g/n with support for WPA/WPA2 encryption
- **UART**: 2 independent UART interfaces for serial communication
- **SPI**: 3 SPI interfaces for high-speed data transfer
- **I2C**: 1 I2C interface for connecting sensors and other peripherals
- **GPIO**: 17 GPIO pins with multiplexing capabilities for various functions like PWM, I2S, and ADC

This diverse range of interfaces enables your ESP32 to connect to all your sensors, actuators, and the Blynk cloud. You can also use them for future expansions like adding a camera, LCD display, or even connecting to other ESP32s for a multi-sensor network.

4. Other Pin Functionalities:

- Analog-to-Digital Converter (ADC): 10-bit ADC for reading analog sensor data
- Pulse-Width Modulation (PWM): 16 PWM channels for controlling motors, LEDs, and other actuators
- Internal pull-up/pull-down resistors: Configurable for input pins

These functionalities let you directly connect and control various components without needing additional circuitry. You can adjust motor speeds, dim lights, and read sensor values with ease.

5. Power Consumption:

The ESP32 is known for its low power consumption, ideal for battery-powered projects. It can enter a deep sleep mode when Wi-Fi is not required, further saving energy. This is crucial for your sustainable farming system, ensuring efficient operation without high energy demands.

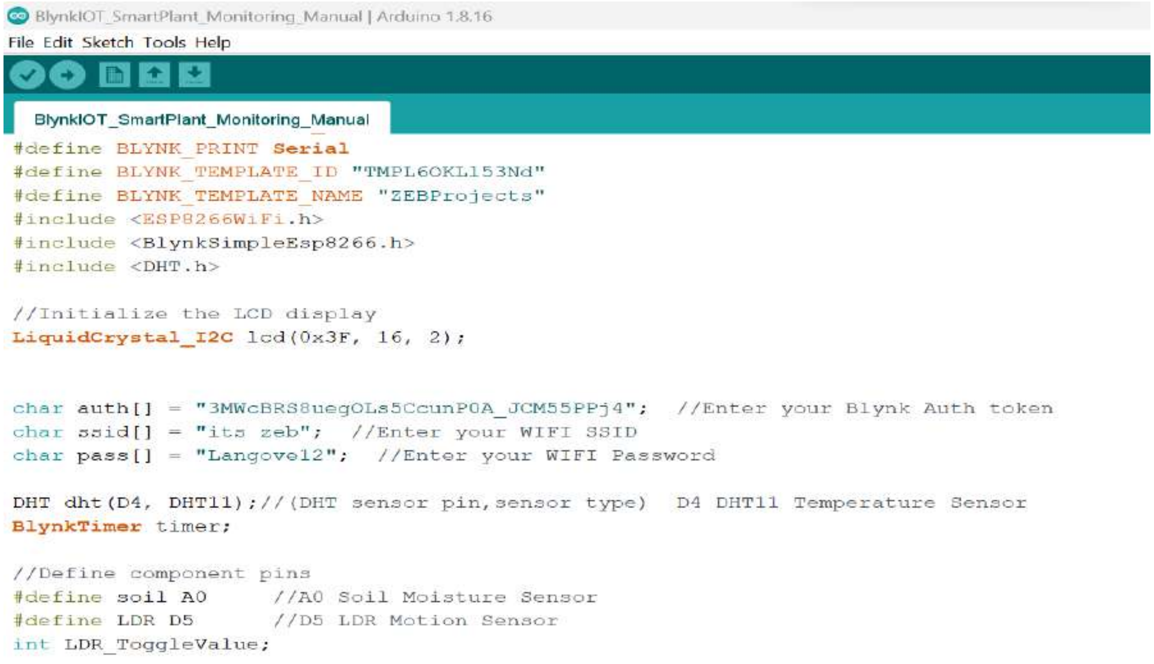
3.2. Developing

The developing phase marks the transition from planning to the actual development and integration of the IoT-based sustainable indoor farming system. This phase encompasses the utilization of identified software and hardware tools to bring the project to fruition.

3.2.1. Software

Arduino IDE Programming

The Arduino IDE serves as the primary platform for programming the ESP32 microcontroller. The codebase is developed to encompass the logic required for data processing, integration of various sensors, and control of actuators. Specialized libraries, including DHT, Blynk, and others, are meticulously incorporated to facilitate seamless interfacing with the selected sensors and actuators.



```
#define BLYNK_PRINT Serial
#define BLYNK_TEMPLATE_ID "TMPL6OKL153Nd"
#define BLYNK_TEMPLATE_NAME "ZEBProjects"
#include <ESP8266WiFi.h>
#include <BlynkSimpleEsp8266.h>
#include <DHT.h>

//Initialize the LCD display
LiquidCrystal_I2C lcd(0x3F, 16, 2);


char auth[] = "3MWcBRS8uegOLs5CcunP0A_JCM55PPj4";  //Enter your Blynk Auth token
char ssid[] = "its zeb";  //Enter your WIFI SSID
char pass[] = "Langove12";  //Enter your WIFI Password

DHT dht(D4, DHT11);//(DHT sensor pin,sensor type)  D4 DHT11 Temperature Sensor
BlynkTimer timer;

//Define component pins
#define soil A0     //A0 Soil Moisture Sensor
#define LDR D5      //D5 LDR Motion Sensor
int LDR_ToggleValue;
```

Figure 3.10: Arduino IDE Interface with some code

3.2.2. Blynk Cloud Integration

The Blynk cloud platform plays a pivotal role in realizing real-time monitoring and data storage capabilities. Integration involves configuring the ESP32 to establish a secure connection with the Blynk cloud, ensuring the efficient transmission and storage of sensor data. This connection allows users to remotely monitor the indoor farming environment through a user-friendly interface.

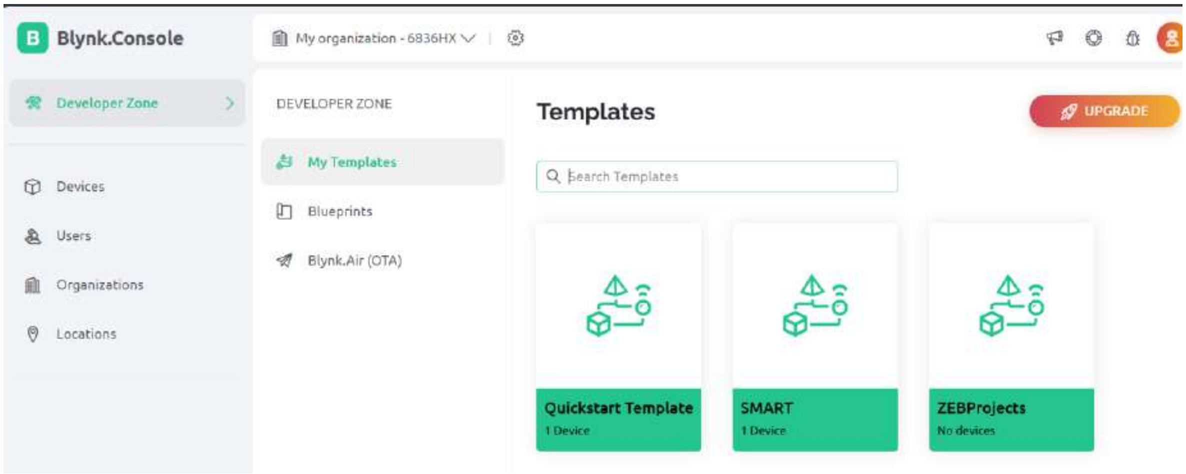


Figure 3.11: Blynk Cloud Developer Zone (Templates) to Integrate with ESP32

3.2.3. Designing Blynk Dashboard

Web development tools are harnessed to create an intuitive user interface accessible via both web browsers and mobile applications. The interface incorporates features such as real-time data visualization, manual controls for actuators, and a historical data tracking mechanism. The design focuses on user-centricity to ensure a seamless and informative experience.

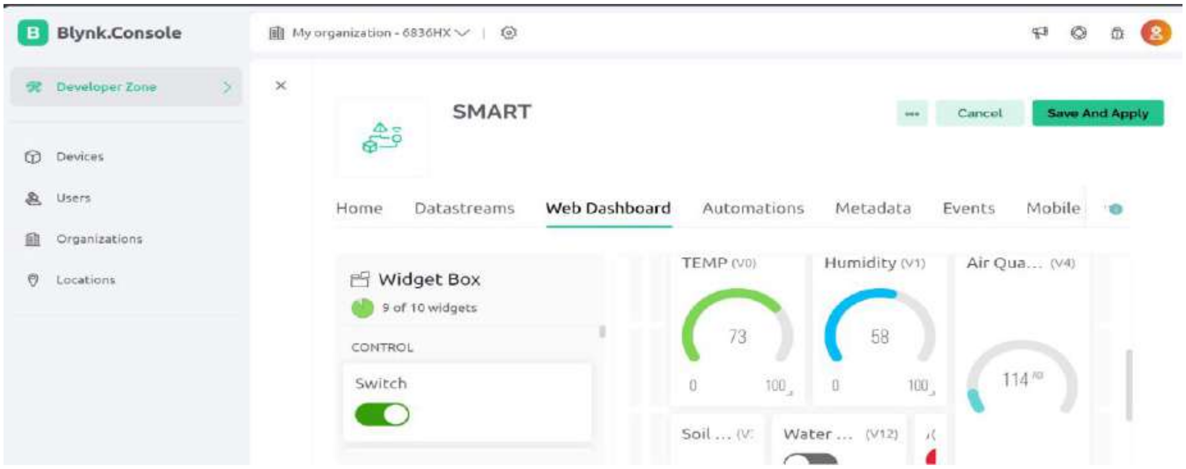


Figure 3.12: Blynk Web Dashboard (Developer Zone)

3.2.4. Setting Up Blynk Application

Download Blynk App:

Install the Blynk application on your mobile device. You can find it on the App Store (for iOS) or Google Play Store (for Android).

Create a Blynk Account:

Open the Blynk app and sign up for a new account. If you already have an account, log in.

Create a New Project:

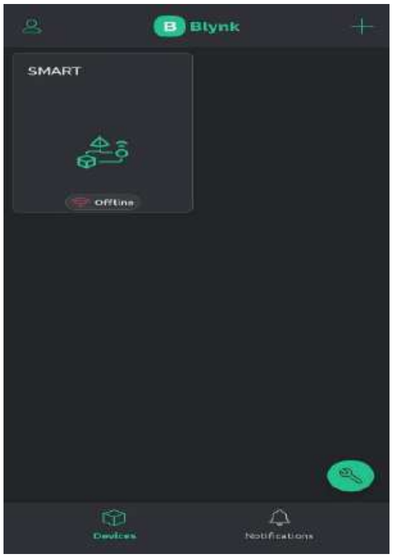


Figure 3.13: Blynk Application Interface

Tap on the "+" icon to create a new project. Give your project a name and select the hardware model (ESP32) you're using.

Get Auth Token:

Once the project is created, an authentication token (Auth Token) will be sent to your email. This token is essential for connecting your ESP32 to the Blynk server.

Add Widgets:

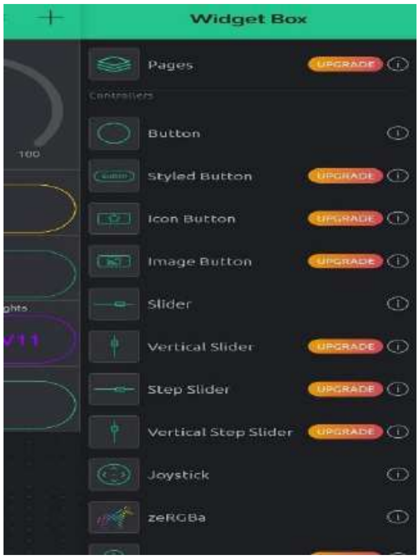


Figure 3.14: Blynk App Widget Box

In the project, you'll see an empty canvas. Tap on it to add widgets. For your project, you might want to add buttons for manual control, display widgets for sensor readings, and maybe a graph for historical data.

Configure Widgets:

Figure 3.15: Blynk App Dashboard view

Each widget needs to be configured. For example, if you're adding a button, you'll link it to a pin on the ESP32. If you're adding a display widget, set it to show the readings from a specific sensor.

Settings for ESP32:

In your Arduino IDE, ensure you have the Blynk library installed. Include the library in your sketch. Use the Auth Token obtained earlier and configure the ESP32 to connect to the Blynk server.

```
#include <BlynkSimpleEsp32.h>

char auth[] = "YourAuthToken";

void setup() {

  Blynk.begin(auth, "SSID", "Password");

}

void loop() {
```

```
  Blynk.run();

}
```

Upload Code to ESP32:

Upload the Arduino sketch to your ESP32 using the Arduino IDE.

Activate Blynk App:

On the Blynk app, press the play button. This establishes a connection between your ESP32 and the Blynk server.

Monitor Your Project:

Figure 3.16: Monitoring and Control on App

You can now monitor and control your smart indoor farming system in real-time through the Blynk app. Check sensor readings, manually control actuators, and observe the system's behavior.

3.2.5. Hardware Implementation

3.2.5.1. ESP32 Microcontroller Deployment

The ESP32 microcontroller, serving as the project's central processing unit, is deployed within the indoor farming environment. Its Wi-Fi capability enables seamless communication with the Blynk cloud and facilitates the collection, processing, and dissemination of sensor data.

Table 3.2: Components Connection with Microcontroller and Virtual Pins (BLYNK).

Components	**Pins (Digital and Analog)**	**Virtual Pins**
DHT11	**D4**	**Temp(V0), Humid(V1)**
Air Quality	**A0**	**V4**
Soil Moisture	**D34**	**V3**
Relay Fan 1	**D13**	**V7**
Relay water Pump	**D15**	**V12**
Relay LED	**D12**	**V11**
Relay Fan 2	**D5**	**V2**

3.2.5.2. Sensor and Actuator Integration

Sensors, including the DHT11, soil moisture sensor, air quality sensor are strategically integrated to collect pertinent environmental data. Actuators, namely the watering system, grow lights, and exhaust fans, are interfaced through relays to enable automated control based on processed sensor data.

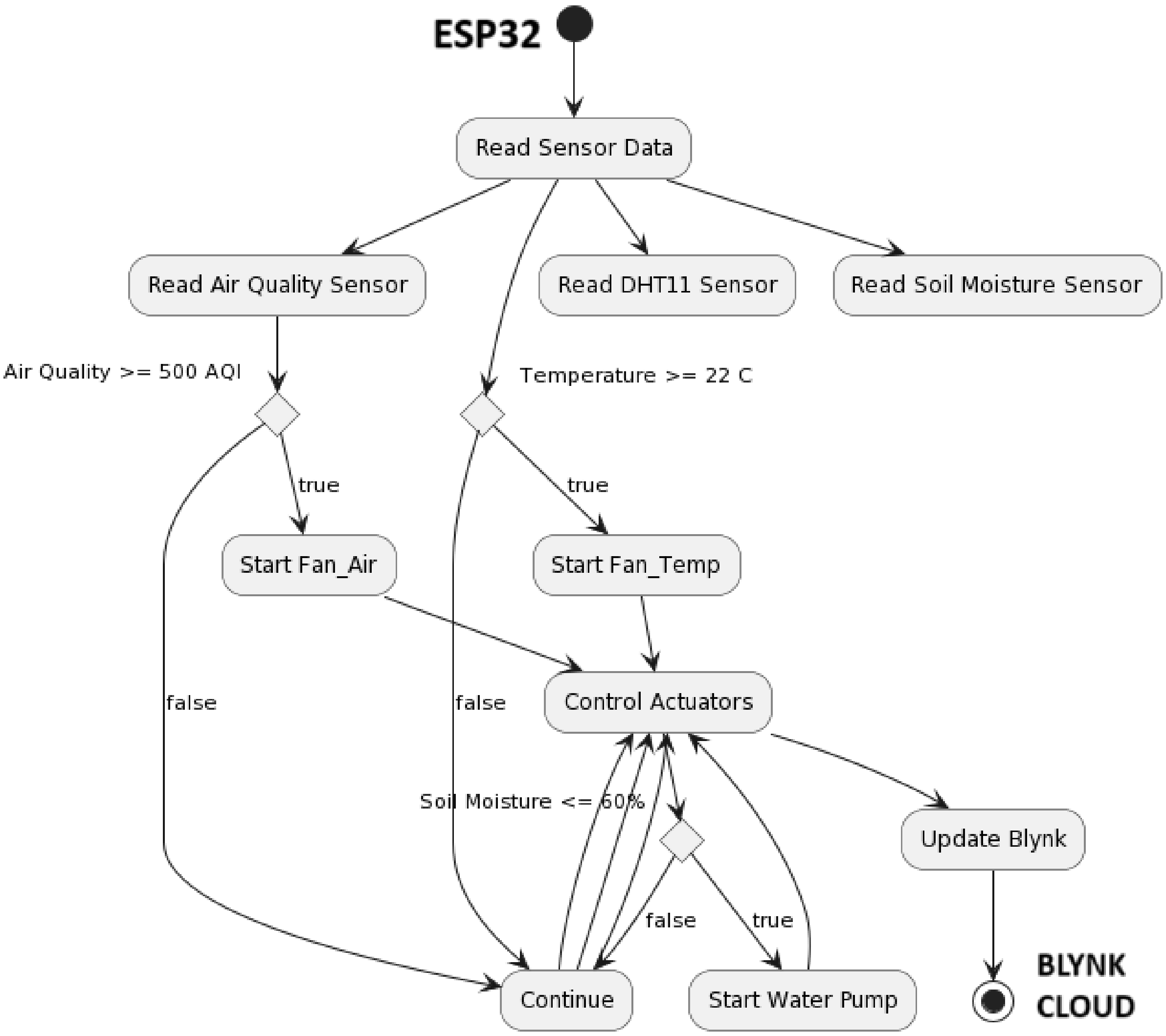


Figure 3.17: Flow chart of the system.

3.2.6. System Architecture

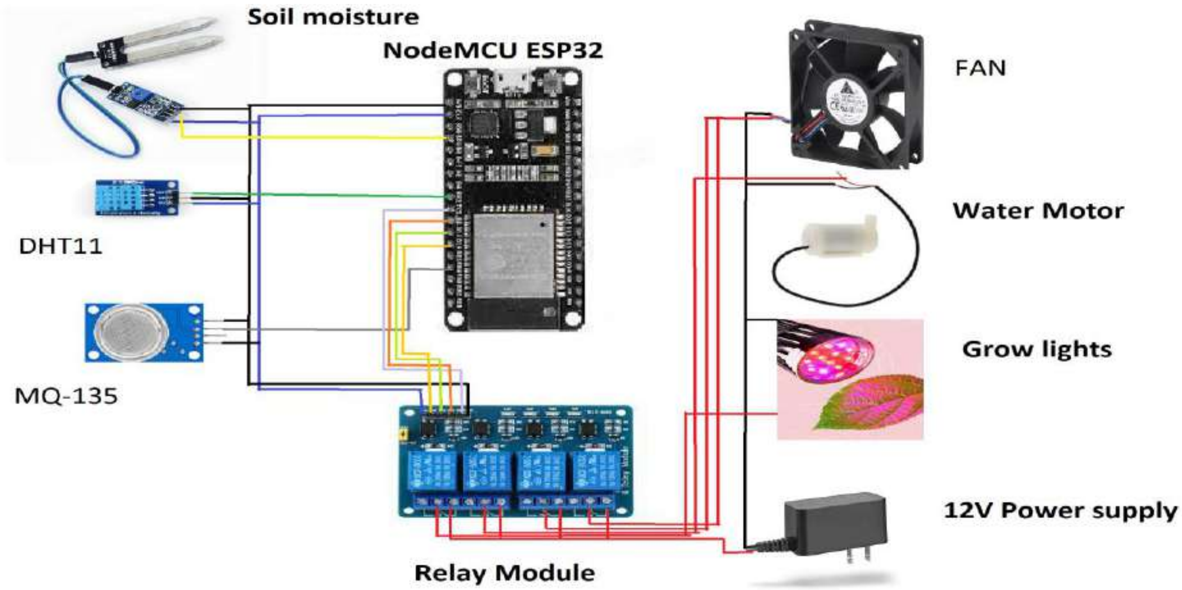


Figure 3.18: The System Architecture.

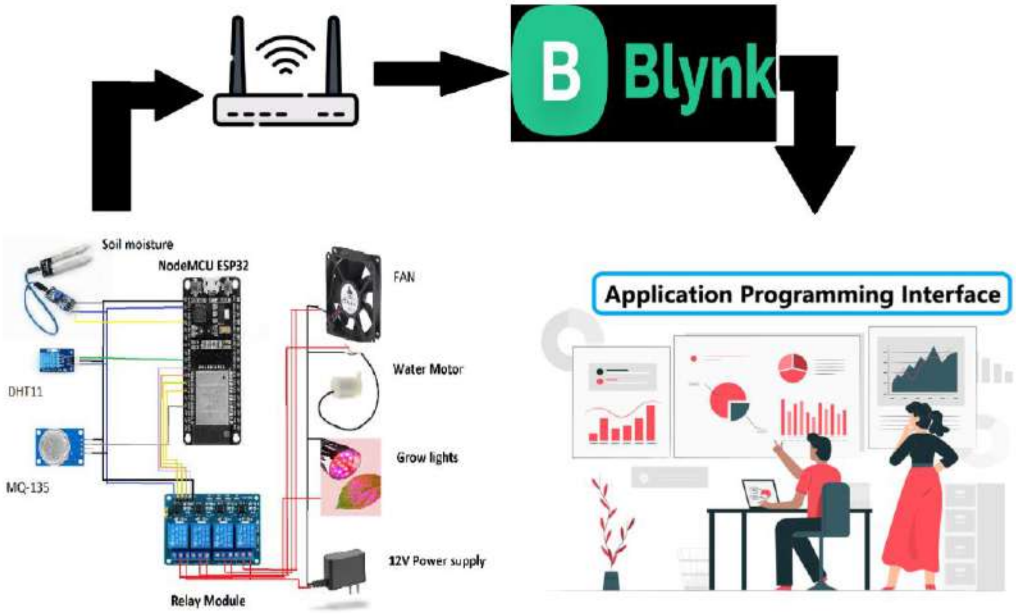


Figure 3.19: Complete workflow of the System Architecture.

3.2.7. User Interface Design and Integration

Blynk Cloud platform is utilized to craft an aesthetically pleasing and functional user interface. The interface allows users to monitor the real-time status of the indoor farming environment, manually control actuators, and review historical data trends. Emphasis is placed on a responsive design to ensure compatibility across various devices.

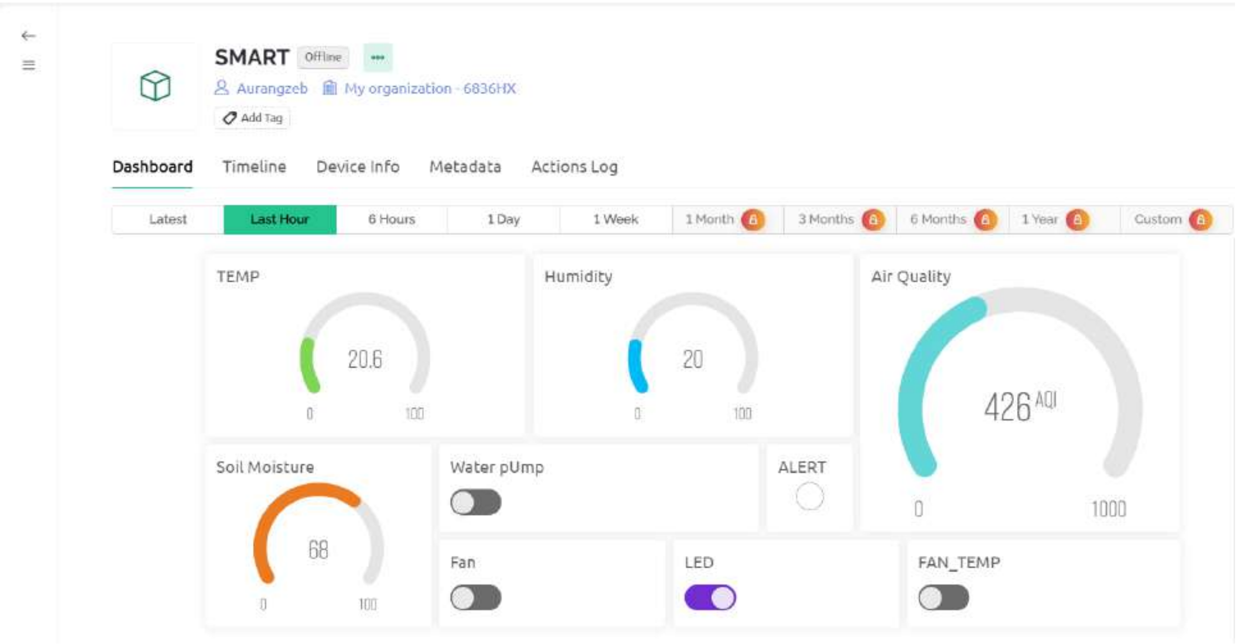
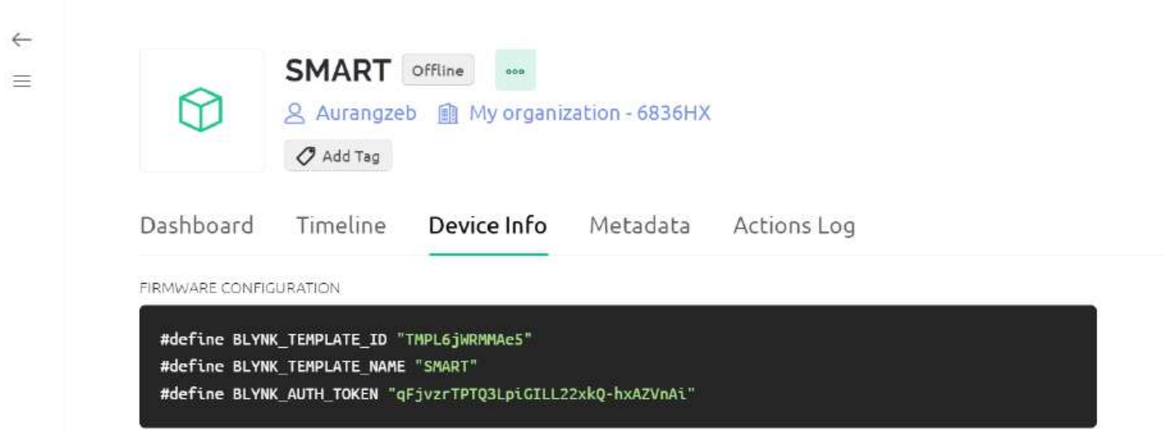


Figure 3.20: User Interface design of Blynk dashboard

The Authentication token, Template name and Template ID are the source units play role in connecting the microcontroller with the cloud platform for a user interface where it can be visualized, monitor and controlled in real time base. The specified credentials are put in the code of the program which later uploaded to the ESP32 microcontroller using the Arduino IDE software.



FIRMWARE CONFIGURATION

```
#define BLYNK_TEMPLATE_ID "TMPL6jWRMMAe5"
#define BLYNK_TEMPLATE_NAME "SMART"
#define BLYNK_AUTH_TOKEN "qFjvzrTPTQ3LpiGILL22xkQ-hxAZVnAi"
```

Figure 3.21: Template ID, Template Name, and Auth Token should be declared at the very top of the firmware code

2. 3.2.8. Prototype Model

3.3.Analysis Phase

The analysis phase constitutes a critical juncture in the System Development Life Cycle (SDLC) where the intricacies and implications of the IoT-based sustainable indoor farming project are thoroughly examined. This phase involves a comprehensive evaluation of various factors, encompassing technical feasibility, economic viability, and the overarching impact on sustainable agriculture.

3.3.1. Technical Feasibility

ESP32 Microcontroller Capability: The technical feasibility hinges on the inherent capabilities of the ESP32 microcontroller. Through meticulous programming in the Arduino IDE, the microcontroller orchestrates data processing, sensor integration, and actuator control. Its WiFi functionality enables seamless communication with the Blynk cloud, facilitating real-time monitoring.

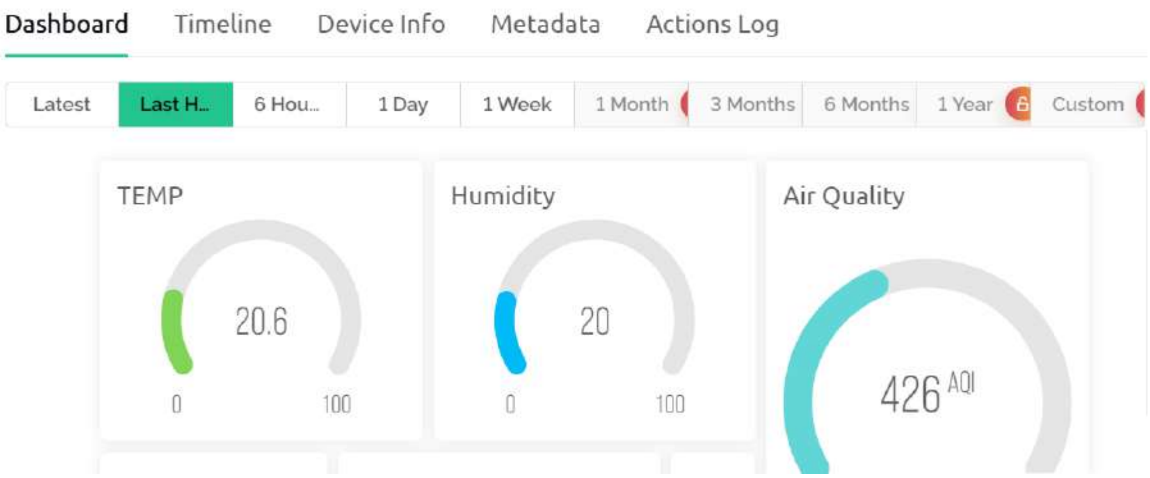


Figure 3.22: Real-time Communication.

Sensor and Actuator Integration: The integration of sensors, including the DHT11, soil moisture sensor, air quality sensor, and presents a technically feasible approach to environmental data collection. The deployment of relays ensures synchronized control of actuators, namely the watering system, grow lights, and exhaust fans, based on processed sensor data.

Blynk Cloud Platform: The utilization of the Blynk cloud platform ensures technical feasibility in terms of data storage, real-time monitoring, and user interaction. The secure connection between the ESP32 and Blynk cloud enables seamless transmission of sensor data and user commands.

3.3.2. Economic Viability

Cost-Benefit Analysis: Economic viability is contingent on a comprehensive cost-benefit analysis. The project involves the acquisition of hardware components (ESP32, sensors, actuators, relays) and software tools (Arduino IDE, Blynk cloud platform). The benefits stem from enhanced resource efficiency, crop yield optimization, and sustainable farming practices.

Return on Investment (ROI): The economic viability is further underpinned by the potential return on investment. The efficient use of resources, automated control mechanisms, and real-time monitoring contribute to the potential economic gains for indoor farming operations.

3.3.3. Impact on Sustainable Agriculture

Resource Optimization: The IoT-based sustainable indoor farming system contributes significantly to sustainable agriculture by optimizing the use of resources. The integration of soil moisture sensors ensures judicious water use, while the automation of grow lights and exhaust fans enhances energy efficiency.

Environmental Impact: The project addresses environmental considerations through the use of an air quality sensor and exhaust fans. These components aid in maintaining optimal environmental conditions for plant growth, minimizing the ecological footprint associated with traditional farming practices.

Alignment with Sustainable Development Goals (SDGs): The project aligns with several Sustainable Development Goals, including Goal 2 (Zero Hunger), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 12 (Responsible Consumption and Production). By promoting efficient resource use and technological innovation, the system contributes to broader sustainability objectives.

3.3.4. Risk Analysis

Technological Risks: Potential technological risks include compatibility issues between sensors, actuators, and the ESP32 microcontroller. Rigorous testing during the implementation phase aims to mitigate these risks.

Operational Risks: Operational risks may arise from user error, system malfunctions, or unforeseen environmental changes. Adequate user training and ongoing maintenance protocols are established to address these risks.

Regulatory and Compliance Risks: Potential risks related to regulatory compliance are assessed, particularly in areas such as data privacy and environmental regulations. The project adheres to existing standards and guidelines to mitigate regulatory risks.

3.3.5. Legal and Ethical Considerations

Data Privacy and Security: Legal and ethical considerations center around data privacy and security. The secure connection between the ESP32 and Blynk cloud, coupled with adherence to privacy regulations, ensures the ethical handling of user data.

Compliance with Environmental Regulations: The project ensures compliance with environmental regulations, addressing ethical considerations associated with sustainable agricultural practices.

3.4.Conclusion

The culmination of Chapter 3 marks the completion of the analysis, planning, and implementation phases within the System Development Life Cycle (SDLC) for the IoT-based sustainable indoor farming project. In this comprehensive exploration, technical feasibility was rigorously assessed, ensuring that the integration of the ESP32 microcontroller, various sensors, and actuators was both effective and efficient. The economic viability of the project was meticulously examined through a cost-benefit analysis, demonstrating the potential return on investment and economic benefits associated with resource optimization in indoor farming practices.

Chapter 4

IMPLEMENTATION AND RESULTS

CHAPTER No. 4. IMPLEMENTATION AND RESULTS

This chapter presents the outcomes of the implemented IoT-based sustainable indoor farming system, combining an analysis of collected data and a thorough discussion of the system's performance in the context of sustainable agriculture.

2. 4.1 Data Collection and Analysis

4.1.1. Environmental Sensor Data

The suite of sensors, including the DHT11, soil moisture sensor, air quality sensor, and consistently recorded crucial environmental parameters. Notable observations include

1. ***Temperature and Humidity Control***

The DHT11 sensor facilitated precise temperature and humidity control, maintaining an environment conducive to plant growth.

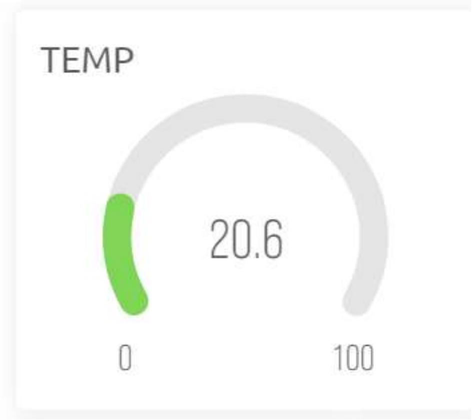


Figure 4.1: Real-Time Temperature data.

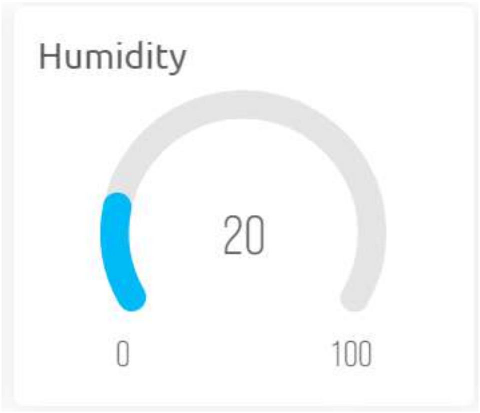


Figure 4.2: Real-Time Humidity data.

2. ***Soil Moisture Optimization***

The soil moisture sensor effectively regulated water usage, preventing over-watering or under-watering and ensuring efficient resource utilization.

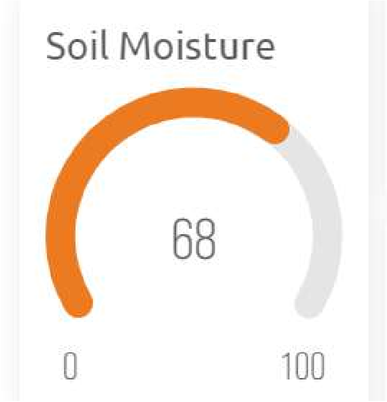


Figure 4.3: Real-Time Soil Moisture Percentage.

3. *Air Quality Management*

The air quality sensor, coupled with the exhaust fans, contributed to sustaining air quality levels essential for plant health.

Figure 4.4: Real-Time Air Quality Value.

4.1.2. User Interaction Data

Interaction data from the user interface, accessible through web browsers and mobile applications, provided valuable insights into user behavior. Key interactions included real-time monitoring, manual control of actuators, and data analysis.

Monitoring and manual control of Actuators

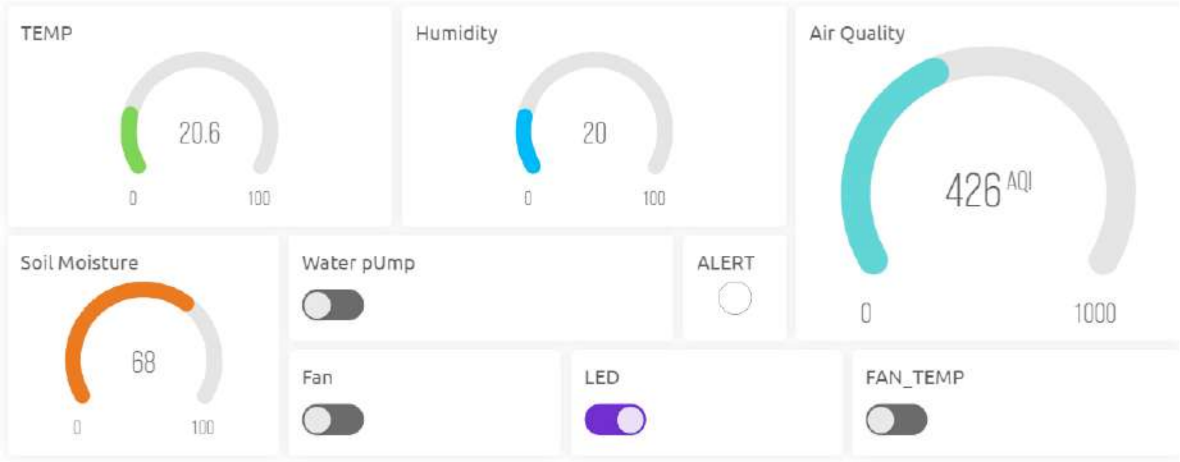


Figure 4.5: Control Buttons and Data visualization on Blynk Dashboard.

3. 4.2 System Performance Evaluation

1. 4.2.1 Real-time Monitoring

The Blynk cloud platform facilitated seamless real-time monitoring, allowing users to access live data streams via a web interface or mobile application. This capability empowered users to make prompt decisions based on the system's status.

2. 4.2.2. Automated Control

Automated control mechanisms for watering, exhausting, and ventilation demonstrated a high degree of accuracy. The relays effectively translated processed sensor data into actionable commands, ensuring a responsive and adaptive system.

3. 4.2.3 Historical Data Trends

The user interface provided historical data trends, enabling users to analyze past environmental conditions. This feature assists in identifying patterns, optimizing resource usage, and making informed decisions for future cultivation cycles.

4. 4.3 Discussion of Results

1. 4.3.1 Sustainable Agriculture Implications

The system's ability to optimize resource use aligns with sustainable agriculture practices. By precisely controlling environmental variables, the project contributes to reducing water wastage, energy consumption, and overall environmental impact.

2. 4.3.2 Economic Benefits

Economic benefits are evident through increased resource efficiency, potential yield optimization, and the reduction of manual labor. The initial investment in the IoT-based system promises long-term gains, reinforcing its economic viability.

3. 4.3.3 User Experience and Adoption

The user-friendly interface and real-time monitoring capabilities enhance the user experience. Initial feedback from end-users indicates a positive response, showcasing the system's potential for widespread adoption in indoor farming.

4. 4.3.4 Addressing Sustainable Development Goals

The project significantly contributes to Sustainable Development Goals, particularly Goal 2 (Zero Hunger), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 12 (Responsible Consumption and Production). The system's emphasis on efficient resource use and technological innovation resonates with global sustainability objectives.

5. 4.4 Limitations and Future Enhancements

1. 4.4.1 System Limitations

While the system exhibits robust performance, limitations include potential connectivity issues, reliance on stable internet access, and dependency on sensor accuracy. Ongoing monitoring and updates are essential to mitigate these constraints.

2. 4.4.2 Future Enhancements

Future enhancements may include integrating advanced machine learning algorithms for predictive analysis, incorporating additional sensors for comprehensive environmental monitoring, and exploring scalability for larger indoor farming setups.

6. 4.5 Conclusion

The Results and Discussion chapter affirms the successful implementation of the IoT-based sustainable indoor farming system. Data analysis validates the system's efficacy in achieving optimal environmental conditions, resource efficiency, and user satisfaction. The discussion contextualizes the results within the realms of sustainable agriculture, economic viability, and global development goals. Acknowledging limitations and proposing future enhancements sets the stage for continuous improvement and innovation in smart indoor farming practices.

Chapter 5

CONCLUSTION

CHAPTER No. 5. **CONCLUSION**

The culmination of this thesis marks the attainment of key milestones in the exploration of IoT-based sustainable indoor farming. As we reflect on the journey from conceptualization to implementation, this chapter encapsulates the core findings, implications, and avenues for future work.

7. 5.1 Synthesis of Key Findings

The deployment of the ESP32 microcontroller, integrated with a suite of sensors and actuators, demonstrated tangible success in creating a responsive and adaptive indoor farming environment. The meticulous data analysis presented in Chapter 4 underscores the system's effectiveness in maintaining optimal conditions for plant growth, optimizing resource usage, and enhancing overall operational efficiency.

8. 5.2 Contribution to Sustainable Agriculture

The project's alignment with Sustainable Development Goals is unmistakable. By championing resource efficiency, reducing environmental impact, and promoting technological innovation in agriculture, the system emerges as a tangible contribution to global sustainability efforts. The implications for sustainable agriculture practices are underscored by the precise control mechanisms that mitigate water wastage, optimize energy consumption, and curtail the environmental footprint associated with traditional farming.

9. 5.3 Economic Viability and User Adoption

Economic benefits arising from increased resource efficiency, potential yield optimization, and reduced manual labor underscore the system's viability in real-world agricultural settings. Positive feedback from end-users regarding the user-friendly interface and real-time monitoring capabilities suggests a promising trajectory for user adoption. As we bridge the realms of technology and agriculture, user acceptance becomes pivotal for the system's integration into mainstream farming practices.

10. 5.4 Lessons Learned and System Improvements

Throughout the project lifecycle, several invaluable lessons were learned. Challenges in connectivity, reliance on stable internet access, and the critical importance of sensor accuracy were identified and addressed. Ongoing monitoring and system updates are acknowledged as essential for mitigating limitations and ensuring the sustained effectiveness of the deployed solution. The iterative nature of technological advancements demands continuous improvement and adaptability.

11. 5.5 Future Directions

The project's success sets the stage for future research and development in smart indoor farming. Integration of advanced machine learning algorithms for predictive analysis, incorporation of additional sensors for more comprehensive environmental monitoring, and exploration of scalability for larger indoor farming setups represent potential avenues for future enhancements.

12. 5.6 Closing Thoughts

In closing, the journey from conceptualization to realization has been both challenging and rewarding. The IoT-based sustainable indoor farming system stands as a testament to the transformative power of technology in reshaping traditional practices. As we navigate an era of environmental consciousness and resource scarcity, this project charts a course towards a more sustainable and technologically empowered future for agriculture.

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1. Code Appendix

```
#define BLYNK_TEMPLATE_ID "TMPL6jWRMMAe5"
#define BLYNK_TEMPLATE_NAME "SMART"
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
#include <DHT.h>

// Credentials and settings
char auth[] = "qFjvzrTPTQ3LpiGILL22xkQ-hxAZVnAi";  //Enter your Blynk Auth token
char ssid[] = "its zeb";  //Enter your WIFI SSID
char pass[] = "Langove12";  //Enter your WIFI Password

DHT dht(4, DHT11); // DHT11 Temperature Sensor, assuming D4 corresponds to GPIO 4
BlynkTimer timer;

// Define component pins
#define soil 34          // Soil Moisture Sensor
#define RELAY_WATERPUMP 15   // Relay for Water Pump, GPIO 15
#define RELAY_FAN 13        // Relay for Fan, GPIO 13
#define RELAY_FAN2 5        // Relay for fan_Temp GPIO5
#define RELAY_LED 12        // Relay for LED, GPIO 12
#define AIR_QUALITY_SENSOR_PIN A0 // MQ135 Sensor, connected to GPIO A0
#define PUSH_BUTTON_1 14    // Physical Button, GPIO 14

// Define virtual pins
#define VPIN_WATERPUMP V12
#define VPIN_FAN V7
```

```
#define VPIN_FAN2 V2

#define VPIN_LED V11

#define VPIN_TEMP V0

#define VPIN_HUM V1

#define VPIN_SOIL V3

#define VPIN_AIR_QUALITY V4 // Virtual pin for air quality



int relayFan2State = LOW;

int relayFanState = LOW;

int relayLEDState = LOW;

int relayWaterpumpState = LOW;

int pushButton1State = HIGH;


void checkPhysicalButton();

void readAirQualitySensor();


void setup() {

  Serial.begin(115200);


  // Initialize relays

  pinMode(RELAY_WATERPUMP, OUTPUT);

  pinMode(RELAY_FAN, OUTPUT);

  pinMode(RELAY_FAN2, OUTPUT);

  pinMode(RELAY_LED, OUTPUT);


  digitalWrite(RELAY_WATERPUMP, relayWaterpumpState);

  digitalWrite(RELAY_FAN, relayFanState);
```

```
  digitalWrite(RELAY_FAN2, relayFan2State);
  digitalWrite(RELAY_LED, relayLEDState);

  pinMode(PUSH_BUTTON_1, INPUT_PULLUP);

  dht.begin();
  Blynk.begin(auth, ssid, pass);

  // Set up timers
  timer.setInterval(2000L, sendSensorData);
  timer.setInterval(500L, checkPhysicalButton);
  timer.setInterval(1000L, readAirQualitySensor);  // Read air quality sensor every second
}

void sendSensorData() {
  // Read humidity and temperature
  float h = dht.readHumidity();
  float t = dht.readTemperature();

  if (!isnan(h) && !isnan(t)) {
    Blynk.virtualWrite(VPIN_TEMP, t);
    Blynk.virtualWrite(VPIN_HUM, h);

    // Control fan based on temperature
    if (t >= 24) {
      relayFan2State = HIGH;
    } else {
      relayFan2State = LOW;
```

```
    }

    digitalWrite(RELAY_FAN2, relayFan2State);
    Blynk.virtualWrite(VPIN_FAN2, relayFan2State); // Update Blynk button status
}
}

void readAirQualitySensor() {
  int airQualityValue = analogRead(AIR_QUALITY_SENSOR_PIN);

  // Process the air quality value as needed
  // For example, you can map the value to a specific range
  int mappedAirQuality = map(airQualityValue, 0, 4095, 0, 1000);

  // Send the air quality value to Blynk
    Blynk.virtualWrite(VPIN_AIR_QUALITY, mappedAirQuality);



  // Control exhaustfans based on Air Quality
  if (mappedAirQuality > 500) {
    relayFanState = HIGH;
    Blynk.virtualWrite(V13, HIGH);
  } else {
    relayFanState = LOW;
    Blynk.virtualWrite(V13, LOW);
  }
  digitalWrite(RELAY_FAN, relayFanState);
  Blynk.virtualWrite(VPIN_FAN, relayFanState); // Update Blynk button status
```

```
  // Read soil moisture
  int value = analogRead(soil);
  value = map(value, 0, 4095, 0, 100);
  value = 100 - value;
  Blynk.virtualWrite(VPIN_SOIL, value);

  // Control water pump based on soil moisture
  if (value <= 60) {
    relayWaterpumpState = HIGH;
  } else {
    relayWaterpumpState = LOW;
  }
  digitalWrite(RELAY_WATERPUMP, relayWaterpumpState);
  Blynk.virtualWrite(VPIN_WATERPUMP, relayWaterpumpState); // Update Blynk button status
}

// Blynk function to control the Water Pump
BLYNK_WRITE(VPIN_WATERPUMP) {
  relayWaterpumpState = param.asInt();
  digitalWrite(RELAY_WATERPUMP, relayWaterpumpState);
}

// Blynk function to control the fan
BLYNK_WRITE(VPIN_FAN) {
  relayFanState = param.asInt();
  digitalWrite(RELAY_FAN, relayFanState);
```

```
}


// Blynk function to control the fan2

BLYNK_WRITE(VPIN_FAN2) {

  relayFan2State = param.asInt();

  digitalWrite(RELAY_FAN2, relayFan2State);

}


// Blynk function to control the LED

BLYNK_WRITE(VPIN_LED) {

  relayLEDState = param.asInt();

  digitalWrite(RELAY_LED, relayLEDState);

}


// Physical button check function

void checkPhysicalButton() {

  if (digitalRead(PUSH_BUTTON_1) == LOW) {

    // pushButton1State is used to avoid sequential toggles

    if (pushButton1State != LOW) {


      // Toggle Relay state

      relayWaterpumpState = !relayWaterpumpState;

      digitalWrite(RELAY_WATERPUMP, relayWaterpumpState);


      // Update Button Widget

      Blynk.virtualWrite(VPIN_WATERPUMP, relayWaterpumpState);

    }

    pushButton1State = LOW;
```

```
  } else {
    pushButton1State = HIGH;
  }
}

void loop() {
  Blynk.run(); // Run the Blynk library
  timer.run(); // Run the Blynk timer
}
```