AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation

by

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LIST OF ABBREVIATIONS

IoT	Internet of Things
AI	Artificial Intelligence
pH	potential of hydrogen
CMB	Single Board Computer
I/O	input/output
RAM	Random Access Memory
IDE	Integrated Development Environ
USB	Universal Serial Bus
CWM	Class Weight Matrix
CWV	Class Weight Vector
EDC	Euclidean Distance to Centriods
IR	Infrared
LDR	Light Dependent Resistor
BLE	Bluetooth Low Energy
MLP	Multilayer Perceptron
LED	Light Emitting Diode
CSV	Comma-Separated Values
iOS	iPhone Operating System
TSMC	Taiwan Semiconductor Manufacturing Company
SRAM	Static Random-Access Memory
SPI	Serial Peripheral Interface
I2C	Inter-Integrated Circuit
UART	Universal Asynchronous Receiver-Transmitter
CAN	Controller Area Network
I2S	Integrated Interchip Sound
SDIO	Secure Digital Input Output
PWM	Pulse-Width Modulation
RH	Relative Humidity

LIST OF SYMBOLS

%	Number of the PLS or PCA component
ms	Millisecond
V	Volt
GHz	Gigahertz
nm	Nanometer
KB	Kilobyte
MB	Megabyte
MHz	Megahertz
°C	Degrees Celsius

Sistem IoT Bersepadu AI untuk Pemantauan Anak Benih Ketepatan dan Automasi Perladangan Pintar

ABSTRAK

Projek ini membentangkan pembangunan Sistem IoT Bersepadu AI untuk Pemantauan Benih Ketepatan dan Automasi Perladangan Pintar untuk menangani cabaran kritikal dalam pertanian moden seperti kebolehubahan iklim dan pengurusan sumber yang tidak cekap. Kaedah pertanian tradisional selalunya memerlukan tenaga kerja, memakan masa, dan kurang ketepatan yang diperlukan untuk pertumbuhan tanaman yang optimum, terutamanya semasa peringkat anak benih. Sistem pertanian pintar sedia ada secara amnya hanya menumpukan pada keadaan asas tumbuhan dan mengabaikan faktor persekitaran yang penting seperti tahap lembapan, pencahayaan dan suhu. Untuk mengatasi batasan ini, sistem ini menyepadukan rangkaian penderia persekitaran berasaskan IoT dengan algoritma kecerdasan buatan untuk menyediakan analisis data masa nyata dan respons automatik. Ia sentiasa memantau suhu tanah, kelembapan, keamatan pencahayaan dan pertumbuhan anak benih, dan menggambarkan maklumat melalui papan pemuka mesra pengguna yang boleh diakses melalui peranti mudah alih. Sistem ini menyokong pembuatan keputusan dengan menjana makluman dan pengesyoran pintar, membolehkan petani bertindak pantas sebagai tindak balas kepada perubahan alam sekitar. Selain itu, ia mengautomasikan tugas kritikal seperti pengairan, mengurangkan pergantungan kepada buruh manual dan meningkatkan kecekapan dalam pengurusan ladang. Dengan menggunakan tenaga suria sebagai sumber kuasa utamanya, sistem ini juga menyokong kemampanan dan mengurangkan kos operasi. Objektif projek termasuk mereka bentuk dan membangunkan sistem pemantauan automatik, menyepadukan AI untuk pengurusan pertanian pintar, dan menguji kefungsian sistem. Tambahan pula, dalam menangani kekurangan buruh dan kesan negatif perubahan iklim. Sistem pertanian pintar bersepadu AI ini berpotensi merevolusikan amalan pertanian tradisional di Malaysia dengan mendayakan keputusan masa nyata, dipacu data, mengurangkan kesan alam sekitar dan menambah baik keseluruhan keluaran pertanian melalui automasi yang mampan.

AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation

ABSTRACT

This project presents the development of an AI-Integrated IoT System for Precision Seed Monitoring and Smart Farming Automation to address critical challenges in modern agriculture, such as climate variability and inefficient resource management. Traditional farming methods are often labour-intensive, time-consuming, and lack the precision required for optimal crop growth, especially during the seedling stage. Existing smart farming systems generally focus only on the basic conditions of plants and ignore important environmental factors such as moisture levels, lighting, and temperature. To overcome these limitations, the system integrates a network of IoT-based environmental sensors with artificial intelligence algorithms to provide real-time data analysis and automated responses. It continuously monitors soil temperature, humidity, lighting intensity, and seedling growth and visualises the information through a user-friendly dashboard accessible via mobile devices. The system supports decision-making by generating intelligent alerts and recommendations, enabling farmers to act quickly in response to environmental changes. In addition, it automates critical tasks such as irrigation, reducing reliance on manual labour and increasing efficiency in farm management. By using solar energy as its primary power source, the system also supports sustainability and reduces operating costs. The project objectives include designing and developing an automated monitoring system, integrating AI for smart agricultural management, and testing the functionality of the system. Furthermore, in addressing labour shortages and the negative impacts of climate change. This AI-integrated smart agricultural system has the potential to revolutionise traditional agricultural practices in Malaysia by enabling real-time, data-driven decisions, reducing environmental impact, and improving overall agricultural output through sustainable automation.

CHAPTER 1 : INTRODUCTION

1.1 Introduction

In the contemporary agricultural landscape, which is progressively influenced by technology, there is a necessity for technical solutions to address numerous current challenges. The AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation project aims to address the primary issues and challenges in contemporary agriculture, including unpredictable climate change, economic difficulties leading to inefficient resource management, and elevated demand for agricultural products. This system integrates technology like the Internet of Things (IoT) and Artificial Intelligence (AI) for thorough automated processes, ranging from seedling surveillance to extensive agriculture.

The majority of smart agricultural automation designs in the agricultural sector fail to meet comprehensive criteria. Current designs focus solely on plant conditions, ignoring other factors such as weather, lighting, water, seedling development, and comprehensive data. Therefore, improvements must be implemented by integrating Artificial Intelligence (AI) and Internet of Things (IoT) technologies into smart agricultural automation to optimise and increase productivity in the agricultural sector.

This method can assist the agriculture sector in making decisions informed by real-time data. Smart sensor technology and AI analysis provide the autonomous monitoring and analysis of data, including soil moisture, ambient temperature and seedling development rate via a dashboard. This technology enables farmers to promptly respond to any discrepancies in the agricultural environment. Consequently, crop production may be enhanced more effectively, hence minimising the wastage of resources such as water and fertiliser.

This technique reduces reliance on human effort, thereby reducing costs and increasing the efficiency of agricultural operations. In situations of labor shortages or rising labor costs, automation through IoT and AI facilitates the systematic and consistent execution of agricultural tasks such as irrigation and crop monitoring. This can increase the production and quality of agricultural goods.

1.2 Problem Statement

Seedling growth issues are influenced by environmental factors, Soil degradation, such as erosion, salinisation, and desertification, along with extreme weather variations like droughts, floods, and heatwaves, severely affect agricultural productivity by depleting soil quality, reducing crop yields, and disrupting food security. For example, the Dust Bowl in the 1930s was caused by over-farming and poor soil management, while recent droughts in Australia and floods in Pakistan have led to massive crop losses, highlighting the destructive interplay between poor soil health and unpredictable weather patterns. In addition, water scarcity due to water resource problems or poor quality is a major issue, especially in areas affected by drought. Finally, there is a lack of trained manpower in the agricultural sector, especially for seedling cultivation.

1.3 Research Objective

There are several objectives in this research that needed to be accomplished to complete this project, which are:

i) To design and develop an automatic seedling monitoring.

ii) To integrate with the technology in seedling monitoring & smart farming management

iii) To validate the functionality of the AI-integrated IoT system for monitoring and predicting the growth of saplings based on data collected from IoT.

1.4 Project Scope

The project involves the creation of an integrated IoT system using artificial intelligence (AI) technology to monitor the size or growth of seedlings, evaluate the data, provide recommendations and enhance the automation capabilities of smart agriculture. The device can monitor sunlight, soil moisture, ambient temperature and soil conditions of seedlings in real time, allowing farmers to access information regularly via the internet to monitor seedlings.

The project emphasises the creation of an intuitive dashboard and automatic notification system that sends critical data, including temperature, lighting, soil moisture and seedling conditions, directly to the phone, facilitating faster and more accurate dissemination of information to farmers and developers. The AI-integrated IoT system for precision seed monitoring and smart agriculture automation uses solar energy as a power source to save costs and reducing environmental degradation can be done through measures such as planting trees to restore ecosystems, reducing plastic use to reduce pollution, sustainable agricultural practices to protect soil, using clean energy to reduce greenhouse gas emissions, and restoring ecosystems such as coral reefs to protect biodiversity.

1.5 Conclusion

The proposal aims to develop and implement electronic components for an AI-Integrated IoT System designed for Precision Seedling Monitoring and Smart Farming Automation, facilitating the agricultural sector and assisting farmers in nurturing seedlings until maturity.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction to Literature Review

This chapter offers an exhaustive analysis of prior research on the amalgamation of AI and IoT technologies in precision seedling monitoring and the automation of smart agriculture. The text examines contemporary literature and research that emphasise the integration of artificial intelligence, IoT applications, and agricultural automation in enhancing seedling growth and farming methods. The study examines IoT-based monitoring systems, AI-driven decision-making, and automation methods in smart agriculture. A comparison is made of the methodology, benefits, and limitations of current systems. The amalgamation of AI with IoT platforms like ESP32-S3 and the utilisation of tools and frameworks to develop effective agricultural systems. The examination of previous studies will facilitate the identification of existing research deficiencies and establish a foundation for the advancement of the proposed AI-integrated IoT system.

2.2 IoT Technology in Smart Agriculture

The Internet of Things (IoT) denotes networks capable of interconnection over the internet for the analysis and transmission of data without direct human involvement. In contemporary agriculture, IoT denotes the utilisation of diverse sensors, intelligent devices, and communication systems to autonomously and instantaneously monitor and regulate agricultural operations, while also integrating AI technology.

This approach enables farmers to acquire precise information on the plant environment, including ambient temperature, light intensity, soil moisture, plant health, and seedling dimensions. The system will then process and evaluate the gathered data with software. According on the assessed data, activities like as fertilisation, irrigation, and notifications can be executed automatically. The subsequent elements in IoT are as follows:

a) Soil Moisture Sensor.

b) Water Pump

c) DHT11 Temperature and Humidity Sensor Module Breakout

d) LED Grow Light Full Spectrum

2.3 Artificial Intelligence (AI) in Agricultural Monitoring

Artificial intellect (AI) is a computational system or instrument designed to do activities that need human intellect or cognition, including the capacity to learn and draw judgements. In agriculture, AI is employed to assess data gathered from many sources, including cameras and sensors, to autonomously monitor soil, seedlings, and environmental conditions. The subsequent kinds utilised in the AI Integrated IoT System project for Precision Seed Monitoring and Smart Agriculture Automation are as follows:

a) Google Colab

b) Support Vector Machine (SVM)

2.3.1 Machine Learning

Machine learning is a component of AI technology that improves many agricultural sectors by regulating and supervising agricultural activities. As a result, it can increase production and improve crop quality. The machine learning methods shown in Figure 2.1 Supervised and unsupervised machine learning allow machines to acquire knowledge about seedling development, agricultural terrain, and environmental conditions. According to Singh & Sobti (2021), when machines acquire knowledge about agricultural operations, they may perform tasks such as temperature forecasting and monitoring. There are several categories of machine learning, in particular.

a) **Supervised learning:** The algorithm utilises a predefined dataset to train an appropriate model for generating predictions. The trained model subsequently correlates all inputs to outputs and does basic evaluations on the outputs, therefore classifying unknown data.

b) **Unsupervised learning:** The algorithm constructs a model utilising unannotated input data. A clustering model categorises items according to their commonalities. Unsupervised learning algorithms analyse extremely similar examples, compute the similarity between new and old samples, and categorise new samples based on similarity.

c) **Sami-supervised learning:** The software trains a model with a little quantity of labelled data alongside a substantial volume of unlabelled data.

d) **Reinforcement learning:** Learning systems acquire behaviour from the environment to optimise the value of the reward signal function. Reinforcement learning contrasts with supervised learning in connectionism by using scalar reinforcement signals from the environment to assess the system's actions, rather than specifying the proper action.

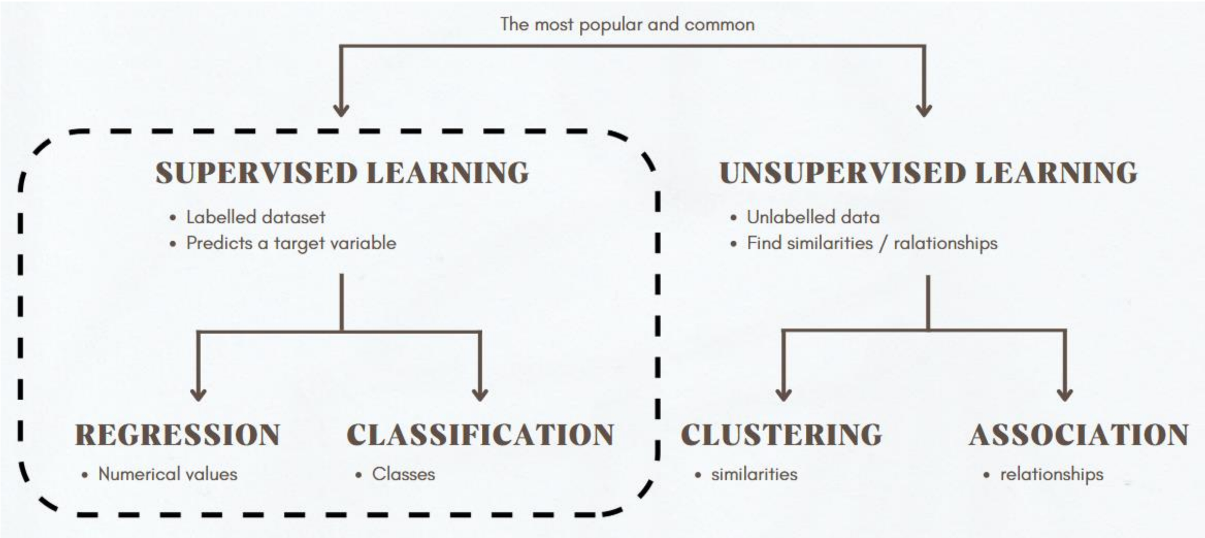

Figure 2.1 Supervised and Unsupervised machine learning

2.4 Seedling Monitoring

Seedling Monitoring is the process of monitoring the development of seedlings from the early stages of germination until they become saplings ready to be transplanted to the main field. This includes monitoring health, growth, and environmental conditions such as light, humidity, and temperature. Table 2.1 shows the parameters used to monitor seedlings until they reach tree size.

Table 2.1 Parameters for monitoring seedlings.

Parameters	Purpose
Seedling maturity	The growth classification ranges from the seedling stage to the tree maturity stage
Leaf Height or Size	Signs of growth growing into a sapling.
Ambient Temperature	Temperatures that are too high/low can damage the seeds.
Soil Moisture	Determine the right time to water when the soil is dry.

2.5 Comparison of Previous Work

Several research studies and existing systems have explored the use of IoT and AI technologies in smart farming applications. Table 2.2 below summarises and compares key aspects of previous works in relation to the objectives of this project.

Table 2.2 Summary of related and comparison Smart farming

METHOD	SYSTEM	PROS	CONS	SOURCE CITATION
IoT	Arduino Mega 2560 Rev3, Arduino Uno Rev3.	- Real-Time Monitoring - Solar-Powered - Multi-Protocol Communication	- Limited Range - Power Limitations - Data Security Risks	(Mahbub, 2020)
IoT AI	Arduino Nano 33 BLE MCU, Raspberry Pi 3B+	- Implements energy-efficient protocols (BLE, LoRaWAN) for long-term operation - Real-time monitoring of air/soil parameters (temperature, humidity, moisture)	- Relies on cellular networks (4G/3G/2G), which may lack coverage in remote rural areas - Limited preprocessing of raw data from low- cost sensors may lead to inaccuracies	(Nawaz & Babar, 2025)
IoT AI	Arduino Uno	- Image processing - Real-time monitoring	- Limited scalability - Resistance to adoption	(Soni, 2020)
IoT	Arduino Nano	- Portable and easy to install in small to medium farms - low-cost, locally available hardware	- Limited scalability outside controlled greenhouse environments - Sensor accuracy limitations - No automated actuator	(Faid et al., 2022)
IoT	Arduino Mega 2560	- Live monitoring facility	- Manually control	(Nayyar & Puri, 2017)
IoT	Arduino UNO R3, Raspberry Pi	- Multi-Sensor Integration - Scalability - Real-time Monitoring	- High Communication Costs	(Farooq et al., 2020)
IoT AI	Arduino	- Drone/UAV integration - Real-time environmental monitoring	- High costs - Limited accessibility - Technical barriers	(Alzubi & Galyna, 2023)
IoT	Arduino Uno	- Energy-efficient solutions - Integration with mobile apps	- Dependence on stable internet connectivity - Ongoing operational costs	(Hemanth Chandra et al., 2024)
IoT	Arduino Uno R3	- Automated responses - Scalable design	- Limited network reliability - High initial costs	(John et al., 2024)

		- Energy-efficient operation		
IoT AI	ATmega32U4	- Integrates AI (LSTM models) - Hybrid power supply (solar/AC) - Low-cost design using open-source software	- Complex setup and maintenance - High energy consumption	(Faid et al., 2022)
IoT	Arduino UNO, Raspberry Pi	- Energy efficiency - Multi-sensor networks	- High initial costs - Sensor vulnerability - - Dependence on	(Priyadharshini et al., 2022)

2.6 Critical Synthesis and Research Gaps

Based on the studies that have been obtained, the study shows that AI and IoT can improve smart agriculture, there are several significant gaps and weaknesses that can be seen, namely the trend of IoT use without AI support. The majority of studies obtained were found to use various IoT sensor systems only. Only a handful of studies actually use AI capabilities to make automatic decisions. The system Mahbub,(2020), for example, only provides real-time monitoring but no seedling health classification mechanism or growth prediction.

In addition, heavy AI model devices are not suitable for use on microcontroller devices, for example, a study (John et al., 2024) that uses AI models such as LSTM, but this is not optimised for low-specification devices such as ESP32 or Arduino. However, there is no clear evidence that these models can or cannot be run well on microcontrollers. Next, there is no study that specifically focuses on seedling monitoring; most studies focus more on automatic crop monitoring, for example, a project by John et al., (2024). There is little research on seedling monitoring.

2.7 Summary

According to Nawaz & Babar (2025), technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) have improved agricultural efficiency, especially in resource-poor areas. In this regard, researchers urge that more studies be conducted to evaluate the long-term effectiveness of IoT-AI systems using continuous learning methodologies and multi-location evaluations to strengthen the sustainability of smart agriculture systems in resource-limited environments. Furthermore, a study by Soni (2020) recommends the creation of integrated IoT-AI systems that include monitoring, forecasting, and automated activities, along with validation models across multiple crops and locations and comprehensive ownership analysis.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

This Methodology chapter seeks to elucidate the approach employed in the construction of the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation in greater depth. The architecture of the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation complies with Malaysian agricultural requirements include efficient irrigation systems like the Muda Irrigation Scheme soil fertility management through fertilizers and crop rotation a skilled labor force for plantation work, effective pest and disease control measures such as integrated pest management the adoption of modern farming technologies like IoT sensors for precision farming. This chapter will also elucidate several sub-topics, including research instrumentation, data analysis, the production of the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation, as well as its installation and subsequent evaluation of effectiveness regarding time, cost, quality, and functionality.

3.2 Implementation Process

The system flow process is a sequential stage in project activity. Prior to project implementation, preliminary planning is essential to ensure the system operates in accordance with the project's flow and primary objectives. Consequently, researchers construct a flowchart that facilitates the identification of the activities and processes inside the project system to ensure the attainment of objectives. Figure 3.1 below illustrates the project system flowchart developed for the AI-integrated IoT system designed for precision seedling monitoring and smart farming automation. Figure 3.1 Flowchart of Project Implementation

3.2.1 Flow Chart

The flowchart illustrates how the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation works. The step-by-step process that the system performs from the start of detection to the final action. The flowchart serves as a blueprint for the algorithm implemented in the ESP32 microcontroller using the Arduino IDE.

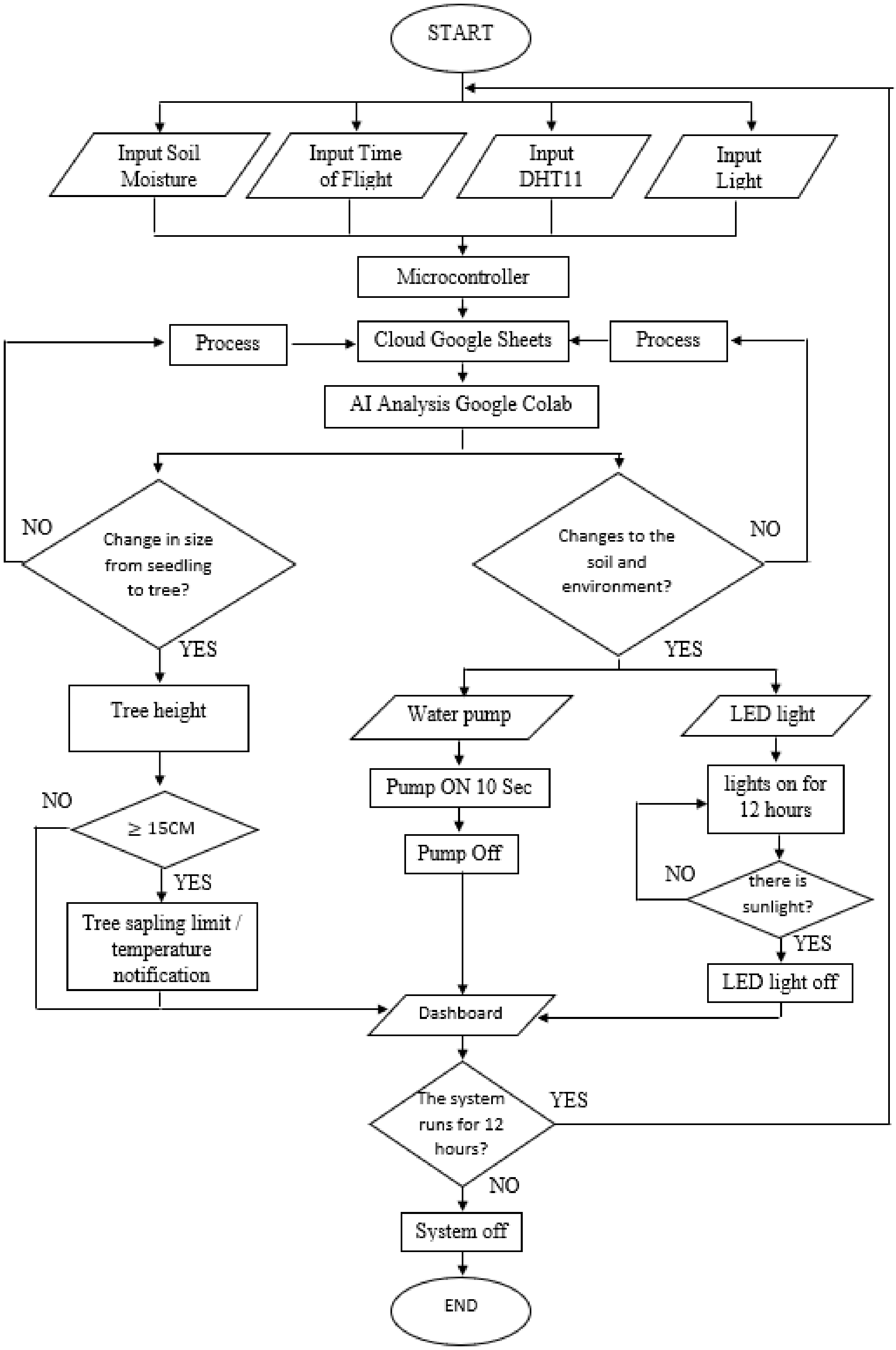

Figure 3.1 Project implementation flowchart

3.2.1.1 Start

The system is powered on by turning the power switch. Once the power is turned on, the microcontroller (ESP32) and all sensors are activated. This prepares the system to start detecting and monitoring environmental and crop conditions.

3.2.1.2 Input Stage

a) Sensors such as the Soil Moisture Sensor, DHT11, BH1750, and Time-of-Flight Sensor are beginning to detect the current conditions of plants and the environment.

b) The data is sent to the microcontroller (ESP32) for processing.

3.2.1.3 Microcontroller Processing

The microcontroller receives input from all sensors and sends this data to the AI Analysis module to make decisions based on the collected data.

3.2.1.4 Collect Data

The microcontroller receives input from all sensors and sends this data to the AI Analysis module to make decisions based on the collected data.

3.2.1.5 AI Analysis

a) Artificial intelligence (AI) systems analyse patterns and changes in data to determine whether action needs to be taken.

b) Tree growth (size from seedling to mature tree).

c) Environmental changes (dry soil, insufficient light, temperatures that are too hot or cold).

3.2.1.6 Decision 1: Is there a change in size?

a) Artificial intelligence (AI) systems analyse data patterns and changes to determine actions such as abnormal environmental temperatures and monitoring saplings.

b) Tree growth (height size from seedling to sapling).

3.2.1.7 Decision 2: Are there any changes to the soil or environment?

If "Yes": System activates automatic response:

a) Water Pump: Turns on for 10 seconds if the soil is dry, then turns off.

b) LED Light: If there is not enough sunlight, the system will turn on the LED light.

3.2.1.8 Sub-decision: LED Lighting Condition

The system will check if sunlight is available. If not, the system will continue to use the LED lights. Next, the system will check the amount of time the plants have received light. If the plants have received enough light (8 hours a day), the LED lights will be turned off.

3.2.1.9 Dashboard

All information, such as sensor readings, pump and LED activity, as well as plant growth status, will be sent directly to the dashboard. This allows users to monitor and check the status of their plants via a digital platform Blynk.

3.2.1.10 End

This cyclical process repeats continuously (loop) as long as the system is in operating mode.

3.3 Project Block Diagram

Figure 3.2 shows the project block diagram for the project AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation.

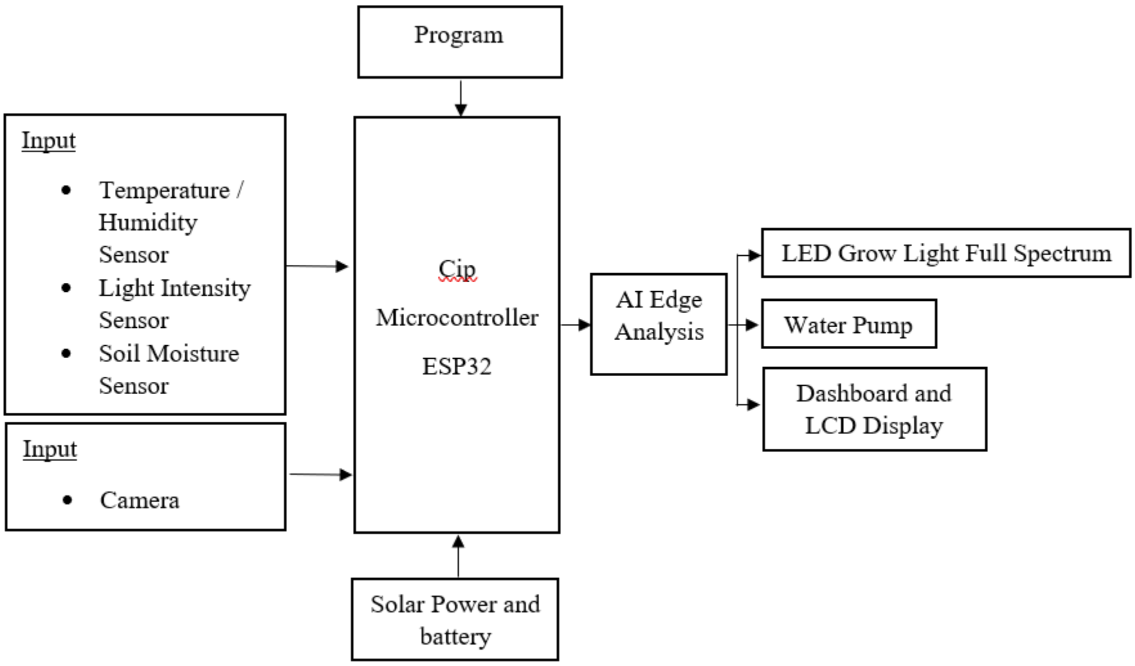

Figure 3.1 Block Diagram AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation

The project design is produced before a program can be developed so that it can be known how the program will fully function in the project. With this project planning, the process of implementing this project can be further facilitated as a result of the studies made in advance. Figure 3.2 shows the project block diagram.

3.4 Prototype Hardware Selection

A Single Board Computer (SBC) is a fully integrated computer built on a single circuit board, containing a microprocessor, memory, input/output (I/O) capabilities, and other essential components for operational functions. Single board computers are often designed for demonstration or development purposes, educational applications, or as embedded computer controllers. Various types of home or mobile computers integrate all of their functions onto a single printed circuit board. Unlike desktop personal computers, single board computers typically do not rely on expansion slots for functionality or peripheral upgrades.

Single board computers have been built with a variety of microprocessors. Basic designs, exemplified by those created by computer enthusiasts, often use static RAM and an economical 8- or 16-bit CPU. Alternative types, such as blade servers, will operate similarly to server computers, albeit in a more compact configuration. Sensor applications span the automotive, construction, mechanical, aerospace, medical, industrial, and robotics sectors. Therefore, sensors will serve as input for this project.

The output from each hardware component in the AI Integrated IoT System for Precision Seedling Monitoring and Smart Agriculture Automation is essential to facilitate watering or fertilization. This section outlines the expected output generated by each major component in the system and explains the output function of each component.

The output from each hardware component in the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation is crucial for facilitating watering or fertilising. This section delineates the anticipated output generated by each principal component inside the system and elucidates the functionality of each component's output.

3.4.1 ESP32-S3-WROOM-1 N16R8

The ESP32-S3 is an open-source platform used for developing electronic projects, Figure 3.3 shows a schematic of the ESP32-S3. ESP32-S3 consists of a physical programmable circuit board, commonly known as a microcontroller, and an Integrated Development Environment (IDE) software. It combines a single Wi-Fi that supports 20 MHz and 40 MHz bandwidth in the 2.4 GHz band and a Bluetooth 5 combo chip, designed with low-power TSMC 40 nm technology, which is used to write and upload code to the physical board. ESP32-S3 also has AI acceleration on the chip for operations such as object detection and image recognition.

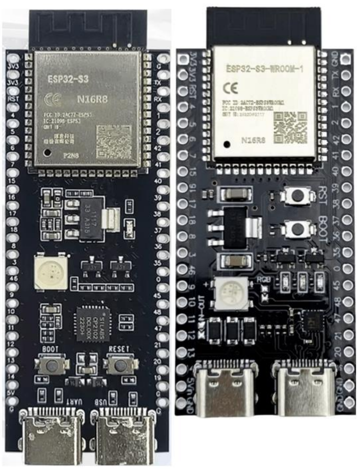

Figure 3.3 ESP32-S3-WROOM-1 N16R8

The ESP32 platform has gained significant popularity among novices in electronics, and justifiably so. In contrast to most prior programmable circuit boards, the ESP32 does not necessitate additional hardware (termed a programmer) to upload new code; this may be accomplished just with a USB cable. The Arduino IDE employs a streamlined variant of C++, facilitating the learning of programming. The ESP32 offers a standardised form factor that simplifies the capabilities of a microcontroller into a more user-friendly device. Table 3.1 encapsulates the characteristics of the ESP32.

Table 3.1 ESP32-S3-Wroom-1 N16R8 Features

Category	**Specification**
Processor (CPU)	Dual-core Xtensa® LX7, up to 240 MHz
Chipset	ESP32-S3 by Espressif Systems
Architecture	32-bit, supports vector instructions for AI/ML acceleration
Wireless Connectivity	2.4 GHz Wi-Fi (802.11 b/g/n) + Bluetooth 5 (LE) with long-range support
Flash Memory	16 MB Quad SPI Flash
PSRAM	8 MB Octal SPI PSRAM
SRAM (internal)	512 KB internal SRAM
AI Acceleration	Built-in vector instructions for neural network and signal-processing workloads
GPIO Pins	Up to 45 programmable GPIOs
Interfaces	SPI, I²C, I²S, UART, PWM, RMT, ADC, DAC, SD/MMC, USB OTG
USB Support	Native USB 2.0 OTG (host/device)
Security Features	AES-256, SHA, RSA, ECC, Secure Boot, Flash Encryption
Operating Voltage	3.0 V – 3.6 V (typical 3.3 V)
Operating Temperature	–40 °C to +65 °C

Antenna Options	Integrated PCB antenna or external (UFL connector, depending on model variant)
Certifications	FCC / CE / SRRC / IC (varies by supplier)
Module Dimensions	18.0 mm × 25.5 mm × 3.1 mm

For ESP32-S3 there are several modules, namely ESP32-S3-WROOM-2, ESP32-S3-WROVER, ESP32-S3-MINI-1, ESP32-S3-DevKitC-1, ESP32-S3-EYE. For the project of AI Integrated IoT System for Accurate Seedling Monitoring and Smart Agriculture Automation, the commonly used module is ESP32-S3-WROOM-1. There are two versions, namely ESP32-S3-WROOM-1 N8R2 and N16R8 for the N8R2 version using 8 MB Flash + 2 MB PSRAM and the N16R8 version using 16 MB Flash + 8 MB PSRAM. Table 3.2 shows the comparison between N8R2 and N16R8.

Table 3.2 Comparison N8R2 and N16R8.

Specifications	**N8R2**	**N16R8**
Flash Memory	8 MB	16 MB
PSRAM	2 MB	8 MB
Flash/PSRAM Interface	Quad SPI	Flash: Quad SPI PSRAM: Octal SPI
Operating Temperature	–40 °C to +85 °C	–40 °C to +65 °C

3.4.2 DHT11 Temperature and Humidity Sensor

The DHT11 sensor as shown in Figure 3.4 DHT11 is used as the main component to measure the temperature and humidity of the environment. DH11 is a digital sensor that can measure the temperature of approximately 0°C to 50°C with an accuracy of 2°C and humidity from around 20% to 90% RH with an accuracy of 5%.

This DHT11 sensor works by reading changes in air humidity and temperature through internal sensor elements, then converting it into a digital signal to ensure that the ESP32-S3-WROOM-1 microcontroller can read the data. Then the data obtained from the DHT11 will be sent serially to the microcontroller system for processing for the purpose of data storage, automation and monitoring. Table 3.3 includes the DHT11 specifications.

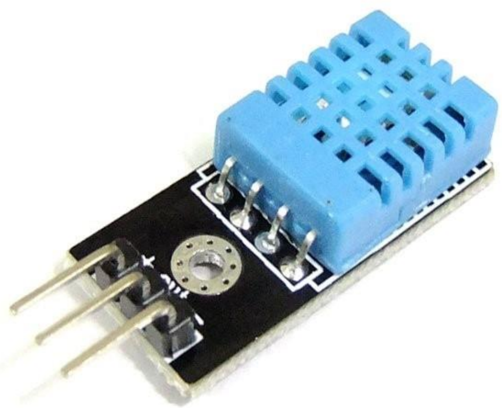

Figure 3.4 DHT11

Table 3.3 DHT11 specification

Parameters	**Reading Range / Value**
Temperature Range	0°C to 50°C
Temperature Accuracy	±2°C
Humidity Range	20% to 90% RH
Humidity Accuracy	±5% RH
Operating Voltage	3.3V – 5.5V
Re-reading Period	1 reading every 1 second (1 Hz)
Output Type	Digital (single-wire protocol)

3.4.3 Light Intensity Sensor

A light intensity sensor like the one in Figure 3.5 is used to measure the ambient light level. The type of sensor used in this project is a Light Dependent Resistor (LDR). This sensor works based on changes in resistance. When the surface of the LDR detects the presence of light, the resistance value will change; the brighter the light, the lower the resistance. This resistance will send data in the form of voltage signals that can be read by a microcontroller such as the ESP32-S3. With this sensor, it can determine whether the planting area is in dark or bright conditions. Table 3.4 Light Intensity Sensor Specification Features

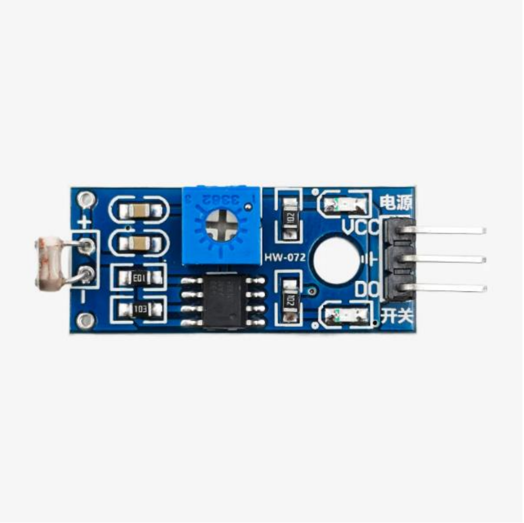

Figure 3.5 Light Intensity Sensor

Table 3.4 Light Intensity Sensor specification

Parameters	**Reading Range / Value**
Sensor Model	BH1750
Measurement Range	1 lux – 65,535 lux
Accuracy	±20%
Output	Digital (I2C interface)
Operating Voltage	3.0V – 5.0V
Response Time	16ms – 120ms
Reading Unit	lux (lumens per meter persegi)

3.4.4 Time-of-Flight (ToF) Sensor (VL53L1X)

A Time-of-Flight (ToF) sensor is a type of distance sensor that works by measuring the time it takes for infrared light using a laser to be emitted to the surface of an object and reflected back to the sensor A Time-of-Flight (ToF) shape as shown in Figure 3.6. The measurement method with the time period taken when the laser is emitted and reflected can determine the actual distance of the object from the sensor very quickly. The main advantages of this sensor are high accuracy, fast response, and is not affected by the color or texture of the object being compared to conventional distance sensors such as ultrasonic. Table 3.5 VL53L1X specification features.

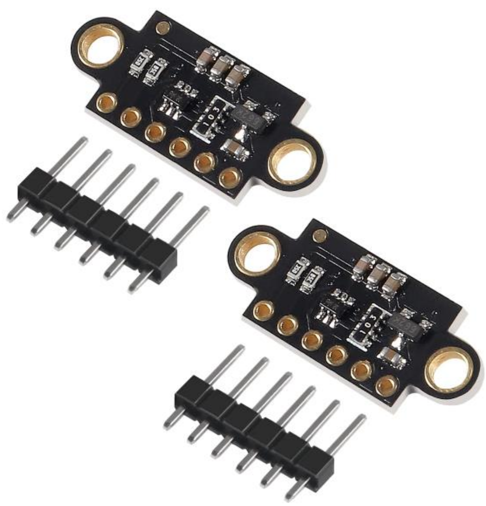

Figure 3.6 Time-of-Flight (ToF) Sensor (VL53L1X)

Table 3.5 VL53L1X specification

Parameters	**Reading Range / Value**
Sensor Model	VL53L1X
Measurement Range	30 mm – 2000 mm
Accuracy	±3% depending on surface conditions
Technology	Infrared (IR) laser
Operating Mode	Continuous / Single ranging

3.4.5 Soil Moisture Sensor

A soil moisture sensor like Figure 3.7 is used to detect the moisture level in the soil., which changes according to the amount of water content in the soil. The higher the soil moisture, the lower the electrical resistance, and the higher the reading will be. The system can identify when the soil is too dry and needs water or when it is moist enough and does not need to be watered. Table 3.6 shows Characteristics of Soil Moisture Sensor specification

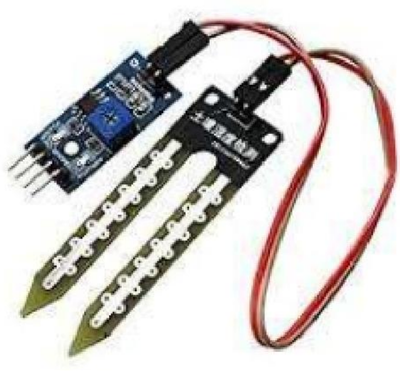

Figure 3.7 YL-69 Soil Moisture Sensor

Table 3.6 Soil Moisture Sensor specification

Parameters	**Reading Range / Value**
Sensor Model	YL-69 Soil Moisture Sensor
Analog Reading Range	0 – 1023 (in 10-bit ESP32 systems)
Soil Moisture Range	0% (dry) – 100% (wet)
Operating Voltage	3.3V – 5V
Technology	Infrared (IR) laser
Output type	Analog and Digital

3.4.6 LED Grow Light Full Spectrum

LED Grow Light Full Spectrum is an LED lamp specially designed for plant growth by providing artificial light similar to the spectrum of sunlight. LED grow lights are used to ensure that seedlings receive an adequate amount of lighting, especially at night, in the rainy season, or when natural light is not enough. This LED lamp contains 3 types of light, namely blue, white and red, which emit spectral waves of 400 nm to 700 nm. Figure 3.10 shows the shape and color of the Full Spectrum LED Grow Light.

Figure 3.8 LED Grow Light Full Spectrum

This LED is suitable for use in the photosynthesis process, root and leaf growth and to accelerate the flowering and fruiting process. When the ambient light reading falls below the minimum set level (for example, < 300 lux), the system will automatically activate the lamp to maintain optimal lighting for tree growth.

Servo motors are used to control mechanical movements such as opening or closing automatic covers in this plant project. SG90 Micro Servo, which is a type of servo that is small, lightweight, and suitable for small-scale automation applications such as FYP projects.

3.4.7 Water Pump

A water pump, or mini-DC water pump, is the main component in an automatic watering system used to flow water from the reservoir to the plants in a controlled manner. The water pump functions as a seedling watering system based on readings from the soil moisture sensor. When the soil moisture is below a set level (for example, < 40%), the water pump will be automatically activated to supply water to the plants. Figure 3.12 shows the type of water pump used: Water Pump R385

Figure 3.9 Water Pump R385 (6 – 12V)

3.5 Power Supply

Smart farming automation systems require a stable and high-power source to effectively operate all components, including sensors and microcontrollers. The power supply system is designed to support low-voltage components while maintaining energy efficiency and reducing environmental pollution for extended operation during testing and deployment.

3.5.1 Solar Panels

Solar panels such as Figure 3.13 function as devices that convert sunlight energy into electrical energy directly using the principle of the photovoltaic effect. Solar panels are used to supply electrical power to smart systems such as ESP32-S3, sensors, water pumps and LED grow lights. Apart from saving electricity, solar can also be used anywhere that has sunlight. In addition, solar is environmentally friendly.

Figure 3.10 Solar Panels (6V,10W)

3.5.2 Battery Charger Module

Battery Charger Module as shown in Figure 3.14 functions as a lithium-ion battery charger module used to control the charging of 3.7V Li-ion or Li-Po batteries safely and efficiently. This module is very suitable for use in small-scale electronic projects such as IoT-based smart agricultural systems because it can be integrated with solar panels. The Battery Charger Module is equipped with safety features such as overcharge protection, over-discharge, and short circuit protection.

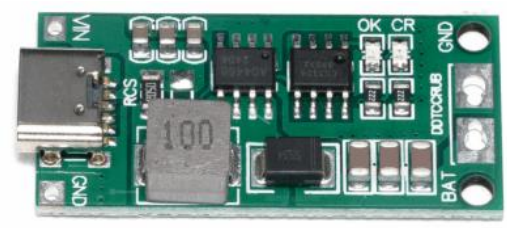

Figure 3.11 Battery Charger Module

3.5.3 MP1584 Buck Module

The MP1584 module is a buck converter, a type of step-down DC-DC converter that efficiently converts a high input voltage to a lower output voltage. This module is particularly useful in FYP projects such as IoT-based smart agriculture systems, where components such as ESP32, sensors, mini water pumps, or LEDs require a certain voltage lower than the main supply source (e.g., a 12V battery). Figure 3.15 shows MP1584.

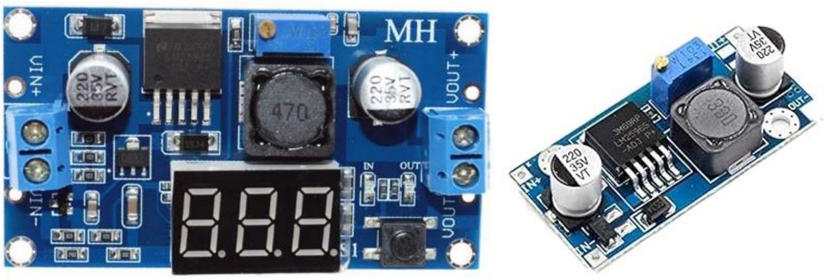

Figure 3.12 MP1584 DC-DC Buck Converter

3.5.4 Lithium 18650 battery

The 18650 lithium-ion battery is a type of high-tech cylindrical battery that is widely used in electronic projects because it is rechargeable, has a high energy capacity, and has a long lifespan. Figure 3.16 shows a type of 3.7v 18650 lithium-ion battery

Figure 3.13 3.7v 18650 lithium-ion battery

3.6 Software

The development of the AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation software involves two main components, including embedded programming using Arduino IDE and Blynk for wireless monitoring. Both systems function to control smart farming automation hardware and provide real-time feedback to users through an easy-to-use interface or website.

3.6.1 Arduino IDE

Arduino IDE is software used to program systems and communication devices via the ESP32-S3 microcontroller. It functions as a platform for writing programs using the C/C++ language and uploading them to the ESP32-S3 board. Through Arduino IDE, you can also check error codes before uploading them to the ESP32-S3 and Arduino IDE also has a Serial Monitor feature that monitors data in real time while the microcontroller is running.

3.6.2 Blynk Application

A platform called Blynk allows users to remotely operate devices like Arduino, Raspberry Pi, and others via iOS and Android apps. By simply dragging and dropping widgets, users may create a graphic interface for their project on a digital dashboard. The user is able to make one or more projects. Each project is capable of including graphical widgets that can communicate with one or more devices, such as virtual LED, buttons, value displays, and even text terminals. With the help of this software, users may turn on and off their lights and check the surrounding lighting levels.

3.6.3 Google Sheet

Google Sheets is a platform for storing, collecting and managing data for the AI-integrated IoT system for precision seedling monitoring and smart farming automation. Data obtained from sensors will be automatically sent to Google Sheets via an internet connection and recorded in real time every 1 minute. This platform will organise each piece of data obtained in the form of a table. The data can also be displayed in the form of graphs to facilitate monitoring and analysis of system performance. In addition, Google Sheets also functions as a lightweight database that supports integration with IoT systems and further analysis for automation and artificial intelligence (AI) purposes.

3.7 Artificial Intelligence (AI) Model Development and Integration

Artificial Intelligence (AI) plays a key role in this project to enable the system to make automated decisions based on sensor inputs and data received. A supervised learning approach is used to train a model to classify the growth stage of seedlings and control automation such as water pumps and LED lights. The model training process is done using a custom data set and this model is then integrated into the ESP32-S3 microcontroller via the Google Colab for Microcontroller format.

3.7.1 Dataset Preparation

a) **Sensor Data Set for Growth Classification:** The sensor data set consists of readings and data collected from the ESP32-S3-based IoT system on the seedling growth environment. The recorded data includes environmental and plant parameters such as ambient temperature, air humidity, soil moisture and seedling height size. Each data received will be labelled into three growth classes, namely seedling, intermediate and mature. The received data set will then be used as input for the training and validation process of the artificial intelligence model for the classification of plant growth stages.

b) **Sensor Dataset for Environmental Control:** Data from sensors such as soil moisture, temperature, air humidity, and light were recorded along with system actions (ON/OFF of pump or LED). This dataset was saved in CSV format and used to train a machine learning model using Google Colab.

3.7.2 Model Training

A Support Vector Machine (SVM) model is used to classify the seedling growth stage based on the collected sensor data set. The model training process is implemented using the Python environment (Scikit-learn) in Google Colab. Before training, the data goes through a pre-processing process that includes data cleaning, feature normalisation and data partitioning into training and test sets. The main parameters for model training are as follows:

i) Algorithm: Support Vector Machine (SVM)

ii) Kernel: Linear / RBF

iii) Data partition: 80% training and 20% testing

iv) Training: Using the Scikit-learn library

The trained SVM model is then used to predict and evaluate seedling growth based on new input data, making it suitable for integration in IoT-based smart agriculture monitoring systems.

3.7.3 Validation Approach

The model was evaluated using the k-fold cross-validation method 5 times to avoid overfitting and increase reliability. In addition, the confusion matrix was used to calculate the accuracy, recall, and F1 score. After that, the model was tested in real situations for 7 days to measure the effectiveness of the system's automatic actions.

3.8 Design Process Model

All the design process is designed to provide a process by which projects can be designed, created, built, tested and improved. Engineers, builders, scientists and designers use the design process to solve a variety of problems. In carrying out project development work, the “Engineering Design Process” model has been used. This model contains five steps for design work in solving a project or problem. Referring to “EiE”, the five steps are:

ASK: What is the problem? How do others approach it? Are there any constraints on you?

IMAGINE: What is the solution? Brainstorm ideas. Choose the best one.

PLAN: Draw a diagram. Make a list of the materials you need.

CREATE: Follow your plan and make something. Test it

IMPROVE: What works? What doesn’t? What could work better? Modify your design to make it better. Test it!

It is important to note that EDP is flexible. There are as many variations of the model as there are engineers. With EiE, students work through all five steps, but in real life, engineers often do only one or two steps, then hand off their work to another team.

Note that EDP is a cycle with no formal start or end point. You can start at any step, focus on just one step, move backward between steps, or follow a cycle. For example, after you have improved your design once, you may want to start it again to improve your technology. You can use EDP repeatedly.

3.9 Ethical and Safety Considerations

In the process of developing an AI-Integrated Internet of Things System for Precision Seed Monitoring and Smart Agriculture Automation, there are several safety and ethical considerations that need to be taken into account. This is done to ensure that the system is safe for the user, plants, and the environment when it is used. Here are some of the ethics and safety:

a) **Prudent and controlled water use:** The system only activates the water pump when the sensor detects soil moisture is below the minimum level set to ensure no water is wasted and can support sustainable resource use.

b) **Electrical equipment safety:** Electronic connections such as water pumps, LED, servo motors and sensors are controlled using low voltage (5V) to avoid the risk of electric shock. Components such as relays and buck converters are used to stabilize the voltage.

c) **System Reliability:** The system is tested in simulated conditions and real environments in a controlled manner to ensure that it functions properly without causing damage to the plants. If a system error occurs, manual override can be performed.

d) **User Safety:** The system is designed so that the user does not need to touch the electrical components directly. The electronic parts are placed in a protective box (enclosure), and moist areas are kept away from the circuit board.

e) **AI Use Ethics:** The AI system is used to make decisions based on sensor data. The data does not involve humans and only focuses on environmental data. There is no privacy violation or sensitive data collection.

CHAPTER 4 : RESULTS & DISCUSSION

4.1 Introduction

This chapter presents the results of the development of an AI Integrated IoT System for Precision Seed Monitoring and Smart Farming Automation. The system is designed to monitor environmental parameters of seedling growth and to automate agricultural actions such as irrigation, fertilisation and lighting based on intelligent decision-making. The results projected in this chapter are in line with the project objectives and the needs identified in the research gaps.

4.2 Sensor data analysis and results

Based on the analysis and results carried out on four types of parameters, namely ambient temperature and humidity, sunlight, soil moisture and seedling height. From these results and analysis, it is shown that this system is able to collect and monitor data from the parameters consistently and directly and in real conditions. Each test result was taken within 10 hours for a week. The data obtained from these sensors is used to assess the growth status of seedlings and determine when to take automatic actions such as watering, turning on lights and dashboards. The results and analysis are presented in Table 4.1showing the results of the four types of parameters and Figure 4.1 the analysis results.

Table 4.1 Data Classification Results using Google Sheets

Date (Time)	Temperature (ºC)	Humidity (%)	Soil moisture (%)	Seedling height (CM)	Growth Stage
4/1/2026 (11:05:00)	30.1	67.6	75	0	Seedling
4/1/2026 (11:15:00)	30	67.6	74	2	Seedling
6/1/2026 (11:05:00)	30.1	67.6	62	3.5	Growing
6/1/2026 (11:15:00)	30	67.6	62	3.1	Growing
09/01/2026 (13:35:00)	29.4	67	65	7.2	Mature
09/01/2026 (13:45:00)	29.4	67	65	7.2	Mature

4.3 Results Based on AI Evaluation

Based on the training and validation of the developed AI model, several evaluation metrics were used to measure the effectiveness and accuracy of the AI system implemented in this project. Two main models were tested, namely the data classification model (using SVM) and the Radial Basis Function (RBF) kernel sensor decision model for classifying the levels. The evaluation results are presented in Table 4.2 and Table 4.3

Table 4.2 Data Classification Results using Machine Learning (ML)

Classification Report:				
Label classes	**Precision**	**Recall**	**F1-score**	**Support**
Growing	0.97	1.00	0.98	86
Mature	1.00	0.97	0.99	36
Seedling	1.00	0.97	0.98	58

Table 4.3 Accuracy of Support Vector Machine (SVM) model.

Classification Report:				
	Precision	**Recall**	**F1-score**	**Support**
Accuracy	-	-	0.98	180
Macro avg	0.99	0.98	0.98	180
Weighted avg	0.98	0.98	0.98	180

Based on the obtained machine learning results, the proposed classification model achieved an accuracy of 0.9833, which is equivalent to 98.33%, based on a total of 180 evaluated samples. Initially, a larger dataset was collected; however, after undergoing a data cleaning process to remove missing values, invalid records, and inconsistent sensor readings such as erroneous temperature, humidity, and soil moisture values, only 180 samples were deemed suitable and retained for model training and evaluation.

The cleaned dataset consisted of three growth stage classes, namely Seedling, Growing, and Mature, with numeric input features including temperature, humidity, soil moisture, motor pump status, LED status, and plant height. These samples were subsequently analyzed and trained using the proposed ML pipeline. Several visual analyses were conducted to support the training process, including the numeric feature correlation with plant height (Figure 4.1), which highlights the relationship between temperature, humidity, and soil moisture; the soil moisture distribution graph (Figure 4.2); and the growth stage versus height trend across samples (Figure 4.3).

The classification performance is further supported by the confusion matrix results (Figure 4.4), which indicate that the model made only three misclassifications out of 180 samples. Specifically, one Mature sample and two Seedling samples were incorrectly classified, while all Growing samples were correctly identified, demonstrating a recall value of 1.00 for the Growing class. Both the Mature and Seedling classes also achieved high precision and recall values above 0.97, confirming the robustness and reliability of the model in distinguishing plant growth stages.

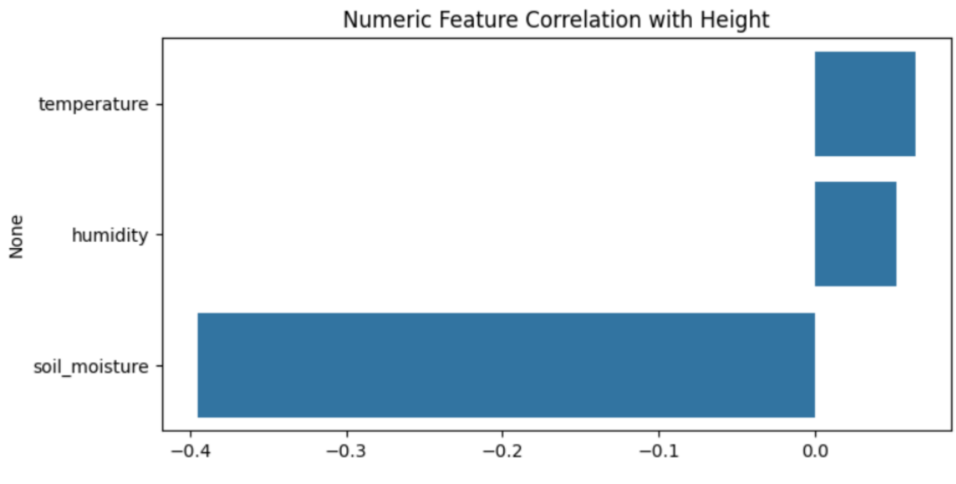

Figure 4.1 Numeric feature correlation with height temperature, humidity, soil moisture

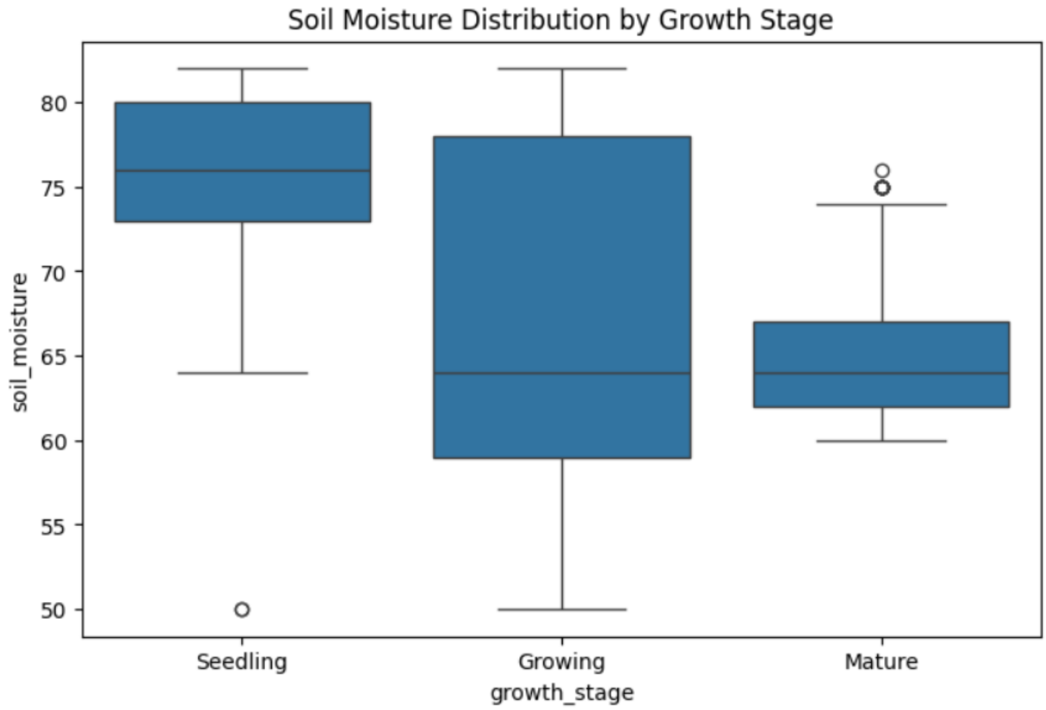

Figure 4.2 Box Plot soil moisture distribution

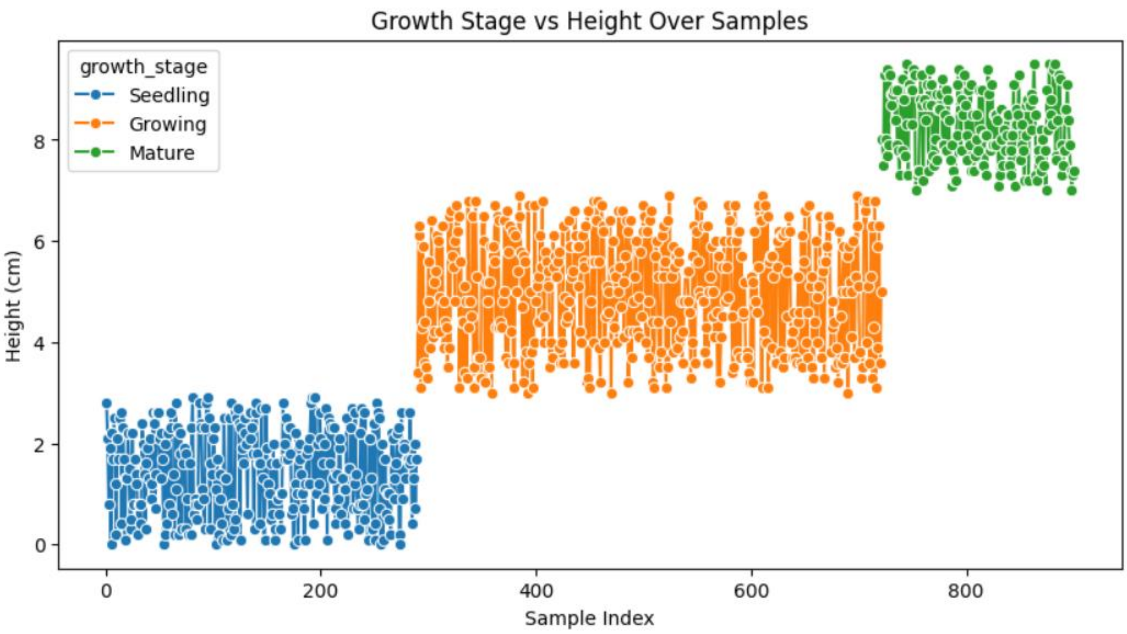

Figure 4.3 Growth stage vs height over 3 samples

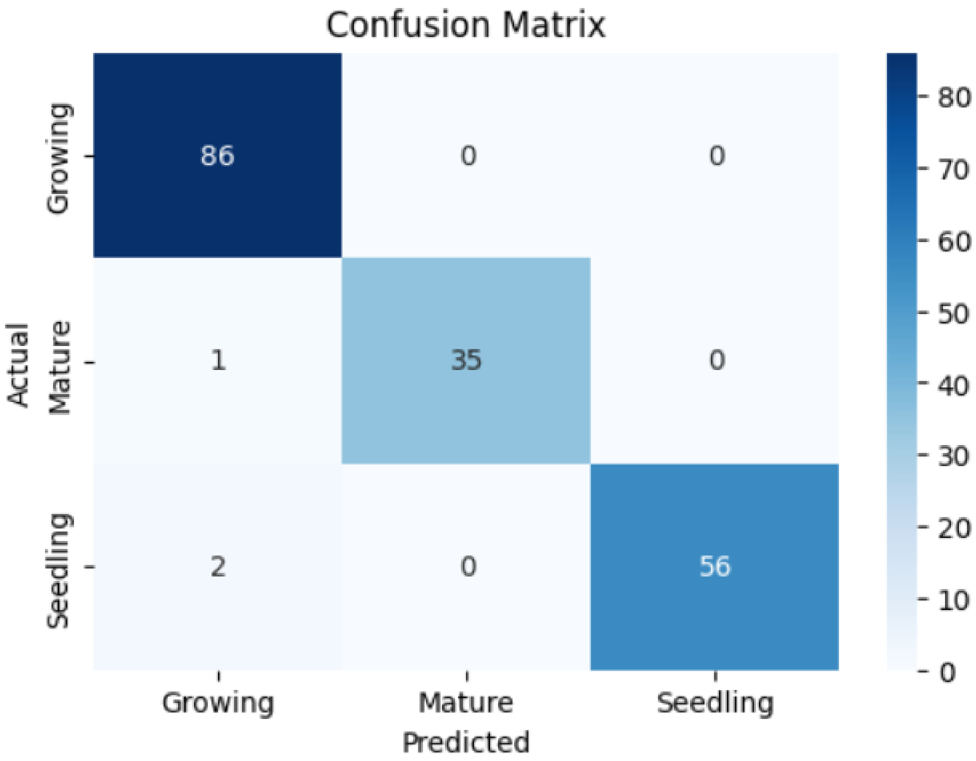

Figure 4.4 Confusion matrix

4.4 Key Performance Indicators (KPIs) and Expected Outcomes

To ensure the system achieves its objectives, several key performance indicators (KPIs) have been set. The KPIs are used to assess the impact of the AI and IoT seed system integration on agricultural efficiency and seedling growth. table 4.3 shows KPI Description, target value, measurement method

Table 4.4 Key Performance Indicators (KPI) for System Evaluation

KPI Description	Target Value	Measurement Method
Accuracy of seedling growth classification by AI (SVM)	≥ 90% accuracy	Analysis of the SVM model (precision, recall)
User Interface Responsiveness	≤ 3 seconds	Display update time test
Frequency of AI visual classification errors	≤ 10% misclassification rate	Analysis using confusion matrix SVM analysis

Based on the set of KPIs, this system is expected to achieve AI (SVM) accuracy of over 90% in growth classification, as well as a Responsive User Interface of at least under 3 seconds. Furthermore, compared to manual control due to more consistent and efficient system response.

4.5 System Testing and Validation Plan

To guarantee the system's stability and the efficacy of the integration of artificial intelligence (AI) with IoT, several testing and validation methodologies have been developed. These assessments encompass system functioning, AI model precision, latency, and performance evaluation in practical settings.

i) Functionality Testing

ii) AI Model Accuracy Testing

iii) Real-World Validation (Field Test)

iv) Data Logging and Analysis

4.6 System Functional Expectations (Functional Results)

The developed system is expected to function as follows:

a) **Real-time data collection:** The system will collect environmental data such as temperature, light intensity, soil moisture, and seedling-to-tree size data using various IoT sensors.

b) **Transmission and Monitoring:** Data information from the sensors will be sent to the microcontroller, and the information will be displayed on the mobile application dashboard in real time.

c) **AI-based Smart Decisions:** Data received by the microcontroller will be sent to AI to analyse the data and predict plant needs, such as expected water in the soil to dry out and expected weather, enabling proactive measures.

d) **Automatic Output Control:** Based on the results of the AI analysis, the system will activate each output, such as the water pump and LED lights, automatically according to the AI analysis in the plant to maintain optimal plant growth.

e) **Notification system:** Users can see the input and output activities of the system in the mobile application dashboard, such as temperature, soil and air moisture readings, seedling size, nutrient levels and ongoing outputs.

4.7 Expected System Advantages

This system is expected to provide various advantages over traditional methods, including:

i) More Accurate Monitoring: Focuses on the care of seedlings that are critical for the survival of the crop.

ii) Reduced Manual Burden: Automatic watering reduces dependence on humans.

iii) More Optimal Water and Fertiliser Use: AI only activates watering when necessary.

iv) Increased Seed Survival Rate: Optimal conditions-maintained help seedlings grow healthily.ied.

v) System Scalability: The system is modular and can be improved for larger farm areas or different types of crops.

4.8 Interface Display (UI/UX)

This display interface is an important component that functions as a medium for displaying notifications between users and IoT systems based on the use of Support Vector Machine (SVM). The Blynk application in this project is used as an interface platform to display sensor data in real time. Figure 4.5 shows several interface display components used to display sensor activity or status.

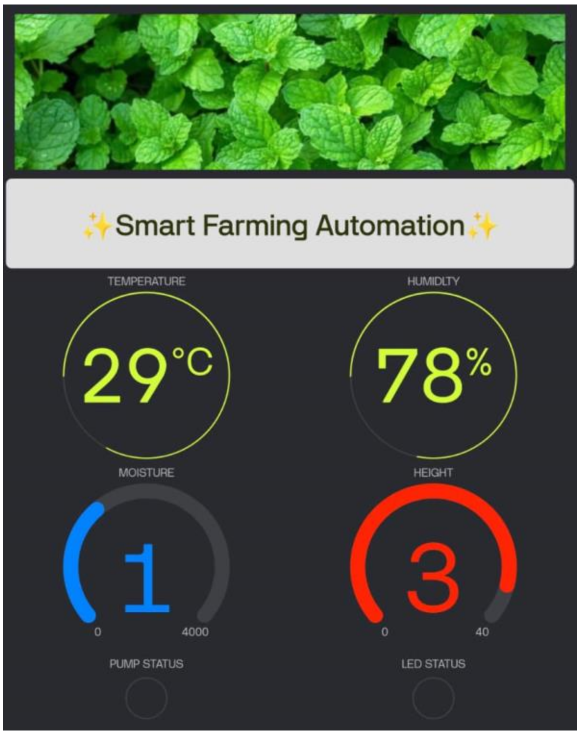

Figure 4.5 Interface Display by Blynk

History The data that will be received in the form of graphs to assist in the use of analysis and identify trends in environmental changes and crop growth over a certain period. Figure 4.5 shows the data in the form of graphs on blynk.

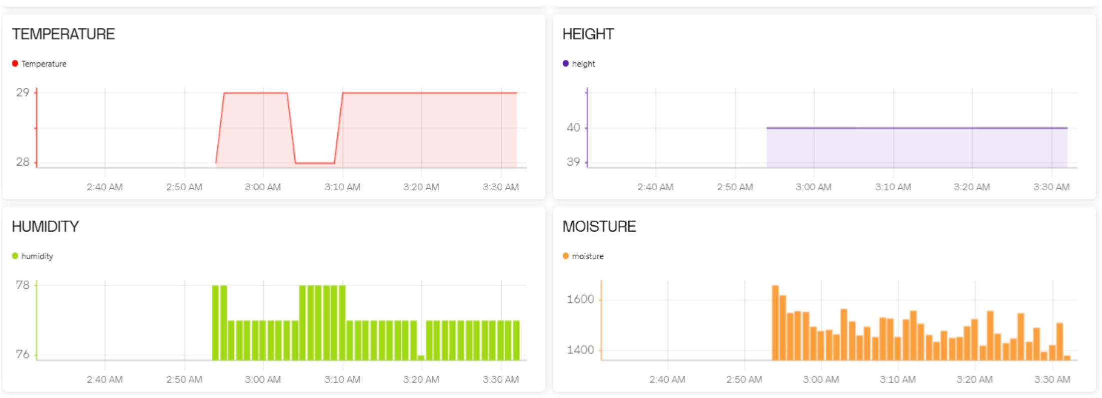

Figure 4.6 Interface Display displays 4 types of graphs by Blynk

4.9 Conclusion

In summary, the expected outcome of this project is a functional smart agriculture prototype by integrating AI and IoT to support accurate seedling monitoring and automated responses. The system is expected to significantly reduce manual workload, cost and improve farming, optimize seedling care, and increase efficiency in small-scale farming or controlled environments. This outcome aligns with the project objectives and addresses key gaps identified in existing smart agriculture systems.

CHAPTER 5 : CONCLUSION

5.1 Introduction

This project focuses on agricultural development and simulation of Smart Farming Automation systems based on IoT and Artificial Intelligence (AI) technology to improve efficiency and user experience in agriculture. The main components include an IoT-based system using an ESP32-S3 microcontroller as the main control unit to collect data from environmental temperature and humidity sensors, soil moisture sensors, and distance sensors to measure seedling height. The data obtained is sent to a cloud platform using Google Sheets for storage and analysis purposes. In addition, AI algorithms are used to classify crop growth levels and support automated decisions such as smart irrigation, thus improving agricultural management efficiency and crop growth quality.

In addition, this Smart Farming Automation system uses a DHT11 sensor to detect air temperature and humidity to monitor the environmental climate, while the Soil Moisture Sensor is used to determine the level of water content in the soil. This IoT-based system utilises the ESP32-S3 microcontroller for real-time data transmission to a cloud server via the Google Sheets platform. Overall, this project demonstrates how the integration of modern technologies such as IoT and sensor-based artificial intelligence (AI) can address the challenge of a shortage of trained labour in the agricultural sector. Although previous studies have only focused on the efficiency of IoT systems, it uniquely proposes AI-based real-time seedling monitoring, addressing inefficiencies in smart farming automation systems while focusing on quality in cultivation.

5.2 Recommendation for Future Project

For future work on this Smart Farming Automation system, several improvements and expansions can be considered to further improve its functionality and efficiency by adding more types of sensors, such as soil and water pH sensors, to obtain a more comprehensive analysis of crop conditions and replacing the ESP32-S3 microcontroller with an ESP-S3 camera because the ESP-S3 camera can communicate well with various other electronic components, including cameras.

In addition, the use of more advanced machine learning algorithms such as Deep Neural Networks (DNN) or Long Short-Term Memory (LSTM) can be considered to enable more accurate predictions of crop growth and irrigation needs based on time-series data. Integration of a more comprehensive cloud platform such as Firebase or AWS IoT can also improve scalability, data security and overall system performance. In addition, the use of machine learning classification is highly encouraged to further improve seedling quality.

Finally, the use of user interfaces with the development of specific mobile applications to make it easier for farmers to monitor crop conditions and receive real-time notifications regarding seedling growth status.

5.3 Commercialization Potential

The AI-Integrated IoT System for Precision Seedling Monitoring and Smart Farming Automation project has high potential for commercialisation in the smart agriculture sector based on high technology to improve the efficiency of monitoring the condition of seedlings in real time through the integration of Internet of Things (IoT) technology and artificial intelligence (AI).

This system is capable of collecting data from various sensors, including temperature sensors, air humidity, soil moisture, sunlight and seedling height. The data is collected and analysed using machine learning algorithms to support the process of monitoring seedling growth and making more accurate automatic decisions. In this way, it can reduce dependence on human labour while at the same time increasing the efficiency of planting output and more organised farm management.

In terms of commercialisation, this system has high potential to be developed as a commercial product in the form of a smart monitoring device or farm management platform based on IoT and AI. This prototype can be offered to small and medium farmers, agricultural institutions and hobby planting enthusiasts as a cost-effective solution to increase crop yields.

Finally, this system has mobile applications, cloud-based data analysis and full farm automation integration. With a cost that is not too expensive and a very easy way for everyone to use the technology, this project has the potential to be widely commercialised and contribute to the development of more modern, efficient and sustainable agriculture.

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APPENDIX A
SAMPLE APPENDIX 1

Budget Expectations

NO	Quantity	Material	Per Unit (Rm)	Total Prive (Rm)
1	3	40-Way 30cm Jumper Wire	3.80	11.40
2	1	Soil Moisture Control Relay Module	16.90	16.90
3	1	DHT11 Temperature and Humidity Sensor	4.90	4.90
4	1	Lithium Battery Charger Board for 3 cell BMS (USB Type-C) 18650 Li-Po LIPO Charging Circuit 4A	2.99	2.99
5	1	PCB, Printed Circuit Board, Donut Board, Matrix Board, Double Sided, 15x20cm, 150x200mm	16.00	16.00
6	1	Relay 1 Channel Relay 5v With Optocoupler Protection For Arduino Nodemcu High Qualiti	4.20	4.20
7	1	BMS (Battery Management System) Li-ion Lithium Polymer LiPo Protection MOS Module Board 18650 3S	3.99	3.99
8	1	R385 Diaphragm Submersible USB Water Pump Motor 12V	11.90	11.90
9	4	PCB Connector (Solder) Terminal Block KF126 KF300, 2-Way & 3-Way 5mm Pitch	0.99	3.96
10	1	DC Step Down XL4015, 5A.max Buck Converter Display Constant Current Module 4015 - 3.3V 5V 9V 12V 24V	7.99	7.99
11	1	Solder Wire 0.5mm	22.99	22.99
12	1	ESP32 S3 w/ SPI PSRAM (N16R8 16M)	38.99	38.99
13	1	18650 Battery Holder Case Box 3 SMT	8.10	8.10
14	1	Photo-resistor LDR Light Sensor Module (Light Dependent Resistor)	2.19	2.19
15	1	M3 PCB Stand Set 6mm/10mm/15mm/20mm	17.50	17.50

16	1	Lampu LED Tanaman USB 5V | Spektrum Penuh | 0.5m - 4m	11.55	11.55
17	1	Breadboard Jumper Wire Set with Casing 140 pcs / 560 pcs For Arduino Prototyping Application	5.15	5.15
18	1	Soil Moisture Control Relay Module Automatic Plant watering Module Plug and Play Module	6.55	6.55
19	1	6V 10W Solar Panal	72.57	72.57
20	1	LM2596s DC-DC buck Converter Step Down Power	13	13
21	4	3.7 18650 Battery Rechargeble Li-Ion	13.95	55.8
22	1	VL53LOX Time-of-Flight Distance Sensor	19.95	19.95
23	1	Waterproof CCTV Cover Enclosure Box | Junction Box | PVC Electrical Box | 4x4 Weatherproof IP67 Outdoor	16.92	16.92
			Total (RM)	375.49

APPENDIX B
SAMPLE APPENDIX 2

Gantt Chart

WEEK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
FYP 1 Briefing	Target																	
	Done																	
Title Selection	Target																	
	Done																	
Literature Review	Target																	
	Done																	
Proposal Preparing	Target																	
	Done																	
Proposal Approval	Target																	
	Done																	
Prototype Designing	Target																	
	Done																	
Programming Constructing	Target																	
	Done																	
Report Submission	Target																	
	Done																	
FYP 1 Presentation	Target																	
	Done																	
Finalize Report Submission	Target																	
	Done																	

APPENDIX C
SAMPLE APPENDIX 3

1. IDE ARDUINO

```
#define BLYNK_TEMPLATE_ID "TMPL6IPEHSXTJ"
#define BLYNK_TEMPLATE_NAME "AI Farming"
#define BLYNK_AUTH_TOKEN "q2a6hL3ITkkbp9Hw73dmgWyuoBzFhVyn"

#include <WiFi.h>
#include <HTTPClient.h>
#include <ArduinoJson.h>
#include <DHT.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <VL53L0X.h>
#include <BlynkSimpleEsp32.h>

// ---------------- LCD ----------------
LiquidCrystal_I2C lcd(0x27, 20, 4);

// ---------------- WiFi & Blynk ----------------
const char* ssid = "IPHONE 17 PRO MAX";
const char* password = "Azam1111";
char auth[] = "q2a6hL3ITkkbp9Hw73dmgWyuoBzFhVyn"; // Ganti dengan token Blynk

// ---------------- OpenWeatherMap ----------------
String URL = "http://api.openweathermap.org/data/2.5/weather?";
String ApiKey = "0e89cd95c00a211987107c36a93a8539";
String lat = "6.460716038346288";
String lon = "100.4303498";

// ---------------- Google Sheets ----------------
String googleScriptURL =
"https://script.google.com/macros/s/AKfycbzKBhxLTlrbGwEskZKKd7u1g91bP5cXKS9pfsE5IkxBhXw1ryMelci52a53T25DG9UwrA/exec";
```

```
// ---------------- DHT ----------------
#define DHTPIN 17
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);

// ---------------- Soil Moisture ----------------
#define MOISTURE_SENSOR_PIN 4
#define RELAY_PUMP 21
int lowWaterThreshold = 2700;
int highWaterThreshold = 2900;
String pumpStatus = "Off";

// ---------------- LDR ----------------
#define LDR_PIN 5
#define RELAY_LIGHT 18
int thresholdNight = 3000;
String lampStatus = "Off";

// ---------------- VL53L0X ----------------
VL53L0X sensor;
float height_cm = 0;

// ================= TIMER =================
unsigned long previousLCDMillis = 0;
unsigned long previousSheetMillis = 0;
const unsigned long lcdInterval = 8000;      // 8 saat
const unsigned long sheetInterval = 120000;  // 2 min

// ==========================================================
void setup() {
  Serial.begin(115200);


  Wire.begin(8, 9);
  lcd.init();
  lcd.backlight();
  lcd.print("Connecting WiFi");
```

```
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    lcd.print(".");
  }

  lcd.clear();
  lcd.print("WiFi Connected");
  delay(1500);

  // Blynk
  Blynk.begin(auth, ssid, password);

  dht.begin();

  pinMode(RELAY_PUMP, OUTPUT);
  pinMode(RELAY_LIGHT, OUTPUT);
  digitalWrite(RELAY_PUMP, LOW);
  digitalWrite(RELAY_LIGHT, LOW);

  if (!sensor.init()) {
    lcd.clear();
    lcd.print("VL53L0X ERROR");
    while (1);
  }
  sensor.startContinuous();
}

// ==========================================================
void loop() {
  Blynk.run(); // wajib untuk Blynk

  unsigned long currentMillis = millis();

  // ---------- SENSOR READ ----------
  float temp = dht.readTemperature();
```

```
float humd = dht.readHumidity();
int moistureValue = analogRead(MOISTURE_SENSOR_PIN);
int ldrValue = analogRead(LDR_PIN);
int dist_mm = sensor.readRangeContinuousMillimeters();
height_cm = dist_mm / 10.0;

// ---------- PUMP ----------
if (moistureValue >= highWaterThreshold) {
  digitalWrite(RELAY_PUMP, HIGH);
  pumpStatus = "On";
} else {
  digitalWrite(RELAY_PUMP, LOW);
  pumpStatus = "Off";
}

// ---------- LAMP ----------
if (ldrValue > thresholdNight) {
  digitalWrite(RELAY_LIGHT, HIGH);
  lampStatus = "Off";
} else {
  digitalWrite(RELAY_LIGHT, LOW);
  lampStatus = "On";
}

// ==================================================
// LCD UPDATE 1 PAGE TERATUR
// ==================================================
if (currentMillis - previousLCDMillis >= lcdInterval) {
  previousLCDMillis = currentMillis;
  lcd.clear();

  // ===== OpenWeatherMap =====
  if (WiFi.status() == WL_CONNECTED) {
    HTTPClient http;
    String fullURL = URL + "lat=" + lat + "&lon=" + lon + "&units=metric&appid=" + ApiKey;
    http.begin(fullURL);
    if (http.GET() > 0) {
```

```
      DynamicJsonDocument doc(2048);
      deserializeJson(doc, http.getString());

      lcd.setCursor(0,0);
      lcd.print(doc["weather"][0]["description"].as<const char*>());

      lcd.setCursor(0,1);
      lcd.print("Temp:"); lcd.print(doc["main"]["temp"].as<float>(),1); lcd.print("C");
      lcd.print(" Hum:"); lcd.print(doc["main"]["humidity"].as<float>(),0); lcd.print("%");
    }
    http.end();
  }

  // ===== VL53L0X =====
  lcd.setCursor(0,2);
  lcd.print("Height:"); lcd.print(height_cm,1); lcd.print(" cm");

  // ===== DHT11 =====
  lcd.setCursor(0,3);
  lcd.print("Temp:"); lcd.print(temp,1); lcd.print("C Hum:"); lcd.print(humd,0); lcd.print("%");
}

// ====================================================
// GOOGLE SHEETS UPDATE SETIAP 2 MINIT
// ====================================================
if (currentMillis - previousSheetMillis >= sheetInterval) {
  previousSheetMillis = currentMillis;
  sendToGoogleSheets(temp, humd, moistureValue, height_cm);
}

// ====================================================
// HANTAR DATA KE BLYNK
// ====================================================
Blynk.virtualWrite(V0, temp);
Blynk.virtualWrite(V1, humd);
Blynk.virtualWrite(V2, moistureValue);
Blynk.virtualWrite(V3, height_cm);
```

```
  Blynk.virtualWrite(V4, pumpStatus == "On" ? 1 : 0);
  Blynk.virtualWrite(V5, lampStatus == "On" ? 1 : 0);
}

// ============================================================
void sendToGoogleSheets(float temperature, float humidity, int soilValue, float heightValue) {
  if (WiFi.status() == WL_CONNECTED) {
    HTTPClient http;

    String url = googleScriptURL;
    url += "?sts=write";
    url += "&srs=Success";
    url += "&temp=" + String(temperature, 1);
    url += "&humd=" + String(humidity, 1);
    url += "&swtc1=" + pumpStatus;
    url += "&swtc2=" + lampStatus;
    url += "&soil=" + String(soilValue);
    url += "&height=" + String(heightValue, 1);

    http.begin(url);
    int httpCode = http.GET();
    Serial.print("Google Sheets HTTP: ");
    Serial.println(httpCode);
    http.end();
  }
}
```

2. APPS SCRIPT

```
// ========================================
// Main function: handle ESP32 GET request
// ========================================
function doGet(e) {

  // ===== DEBUG SAFETY =====
  if (typeof e === 'undefined') {
    e = {
      parameter: {
```

```
      sts: "write",
      srs: "OK",
      temp: "30",
      humd: "70",
      swtc1: "ON",
      swtc2: "OFF",
      soil: "2000",
      height: "12"
    }
  };
}

var sheet_id = '1O5rdEHPv_VUIlthdFadlE9EY3_ATJfsdd7dP2Y4_VyI';
var sheet_name = "ESP32_Google_Sheets_Sheet";
var sheet = SpreadsheetApp.openById(sheet_id).getSheetByName(sheet_name);

var newRow = sheet.getLastRow() + 1;

// ===== 10 Kolum (A - J) =====
var rowDataLog = new Array(10);

var Curr_Date = Utilities.formatDate(new Date(), "Asia/Kuala_Lumpur", 'dd/MM/yyyy');
var Curr_Time = Utilities.formatDate(new Date(), "Asia/Kuala_Lumpur", 'HH:mm:ss');

rowDataLog[0] = Curr_Date; // A
rowDataLog[1] = Curr_Time; // B

var sts_val = "";
var height_val = 0;

for (var param in e.parameter) {
  var value = stripQuotes(e.parameter[param]);
  switch (param) {
    case 'sts': sts_val = value; break;
    case 'srs': rowDataLog[2] = value; break;
    case 'temp': rowDataLog[3] = value; break;
    case 'humd': rowDataLog[4] = value; break;
```

```
    case 'swtc1': rowDataLog[5] = value; break;
    case 'swtc2': rowDataLog[6] = value; break;
    case 'soil': rowDataLog[7] = value; break;
    case 'height':
      height_val = parseFloat(value);
      rowDataLog[8] = height_val; // I
      break;
  }
}

// ===== KIRA TINGGI & KELAS =====
var plantHeight = 37 - height_val;
var plantClass = "";

if (plantHeight < 3) {
  plantClass = "Seedling";
} else if (plantHeight < 7) {
  plantClass = "Growing";
} else {
  plantClass = "Mature";
}

rowDataLog[9] = plantClass; // J

// ===== WRITE DATA =====
if (sts_val == 'write') {
  sheet.getRange(newRow, 1, 1, rowDataLog.length)
       .setValues([rowDataLog]);

  return ContentService.createTextOutput("Write Success");
}

// ===== READ DATA =====
if (sts_val == 'read') {
  var allData = sheet.getRange('A2:J' + sheet.getLastRow()).getValues();
  return ContentService.createTextOutput(JSON.stringify(allData));
}
```

```
  return ContentService.createTextOutput("No valid sts parameter");
}

// =============================================
// Utility function
// =============================================
function stripQuotes(value) {
  return value.replace(/^["']|["']$/g, "");
}
```

3. PYTHON CODE

```
# ============================================================
# Smart Farming Automation: Full Pipeline + SMOTE + MLP + Visualisasi
# ============================================================

import pandas as pd
import numpy as np
from sklearn.preprocessing import LabelEncoder, StandardScaler
from sklearn.model_selection import train_test_split
from sklearn.metrics import classification_report, accuracy_score, confusion_matrix
from sklearn.impute import SimpleImputer
from imblearn.over_sampling import SMOTE
import tensorflow as tf
import pickle
import matplotlib.pyplot as plt
import seaborn as sns

# ============================================================
# 1️⃣ Load CSV & Bersihkan
# ============================================================
data = pd.read_csv("Smart Farming Automation.csv", encoding="latin1", skiprows=1)

# Bersihkan nama lajur
data.columns = (
    data.columns
    .str.strip()
    .str.lower()
    .str.replace(" ", "_")
    .str.replace("(", "")
    .str.replace(")", "")
    .str.replace("°", "")
)

# Rename columns khusus untuk ML
data.rename(columns={
    'temperature_¡c': 'temperature',
```

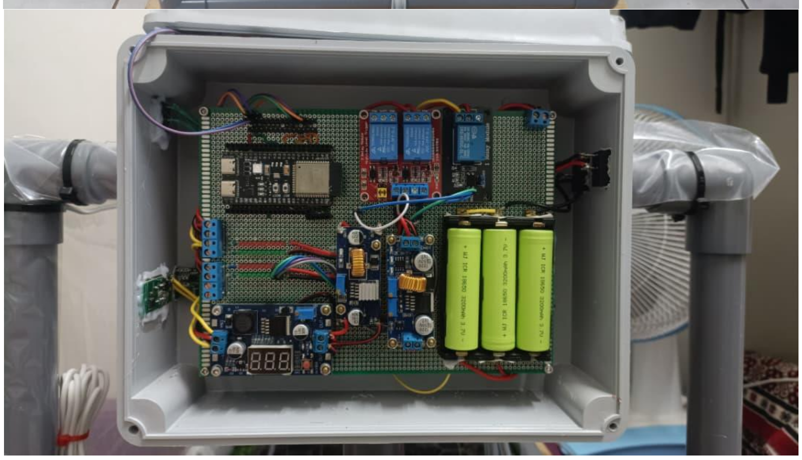
```
    'humidity_%': 'humidity',
    'height_cm': 'height'
}, inplace=True)

# Encode growth_stage
label_encoder = LabelEncoder()
data['growth_stage'] = label_encoder.fit_transform(data['growth_stage'])
classes = label_encoder.classes_

# ============================================================
# 2 Preprocessing: Missing Values + Encode
# ============================================================
numeric_cols = ['temperature', 'humidity', 'soil_moisture', 'height']
num_imputer = SimpleImputer(strategy='mean')
data[numeric_cols] = num_imputer.fit_transform(data[numeric_cols])

binary_cols = ['motor_pump', 'led']
cat_imputer = SimpleImputer(strategy='most_frequent')
data[binary_cols] = cat_imputer.fit_transform(data[binary_cols])

# Map motor_pump & led ke 0/1
for col in binary_cols:
    if data[col].dtype == 'object':
        data[col] = data[col].map({'On': 1, 'Off': 0})

print("\nMissing values selepas imputation:")
print(data.isnull().sum())

# ============================================================
# 3 Feature Selection
# ============================================================
feature_cols = ['temperature', 'humidity', 'soil_moisture', 'height', 'motor_pump', 'led']
X = data[feature_cols]
y = data['growth_stage']

# Standardize numeric features
scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)

# Split train/test
X_train, X_test, y_train, y_test = train_test_split(
    X_scaled, y, test_size=0.2, random_state=42, stratify=y
)

# ============================================================
# 4 Handle Imbalance with SMOTE
# ============================================================
smote = SMOTE(random_state=42)
X_train_res, y_train_res = smote.fit_resample(X_train, y_train)

print("\nDistribusi kelas selepas SMOTE:")
print(pd.Series(y_train_res).value_counts())

# ============================================================
```

```
# 5 Train TensorFlow MLP
# ==========================================================
model = tf.keras.Sequential([
    tf.keras.layers.Dense(64, activation='relu', input_shape=(X_train_res.shape[1],)),
    tf.keras.layers.Dense(32, activation='relu'),
    tf.keras.layers.Dense(len(classes), activation='softmax')
])

model.compile(
    optimizer='adam',
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy']
)

history = model.fit(
    X_train_res, y_train_res,
    validation_split=0.2,
    epochs=50,
    batch_size=16,
    verbose=1
)

# ==========================================================
# 6 Evaluate Model
# ==========================================================
y_pred = model.predict(X_test).argmax(axis=1)

print("\nAccuracy Test Set:", accuracy_score(y_test, y_pred))
print("\nClassification Report:")
print(classification_report(y_test, y_pred))

# Confusion Matrix
cm = confusion_matrix(y_test, y_pred)
plt.figure(figsize=(5,4))
sns.heatmap(cm, annot=True, fmt='d', cmap='Blues', xticklabels=classes, yticklabels=classes)
plt.xlabel("Predicted")
plt.ylabel("Actual")
plt.title("Confusion Matrix")
plt.show()

# ==========================================================
# 7 Visualisasi
# ==========================================================

corr_with_height = data[numeric_cols].corrwith(data['height'])
plt.figure(figsize=(6,4))
sns.barplot(x=corr_with_height.index, y=corr_with_height.values)
plt.title("Numeric Feature Correlation with Height")
plt.ylabel("Correlation")
plt.show()

plt.figure(figsize=(6,4))
sns.boxplot(x='growth_stage', y='soil_moisture', data=data)
plt.xticks(ticks=range(len(classes)), labels=classes)
plt.title("Soil Moisture Distribution by Growth Stage")
```

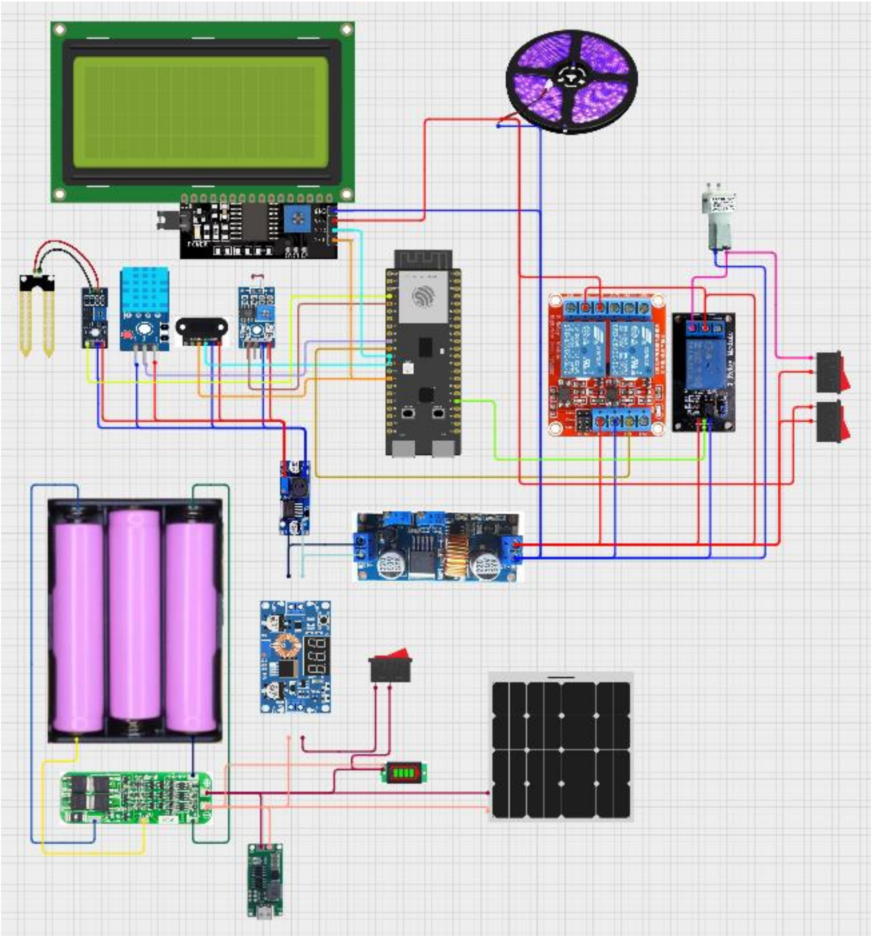
```
plt.show()

plt.figure(figsize=(8,5))
sample_data = data.groupby('growth_stage', group_keys=False).apply(lambda x: x.sample(n=3, random_state=42))
sns.scatterplot(x=sample_data.index, y='height', data=sample_data, hue='growth_stage', palette='Set2', s=100)
plt.title("Growth Stage vs Height Over Samples")
plt.ylabel("Height (cm)")
plt.xlabel("Sample Index")
plt.legend(title="Growth Stage", labels=classes)
plt.show()

# ==========================================================
# 8️⃣ Simpan Model & Scaler
# ==========================================================
model.save("smart_farming_model_balanced.h5")
with open("scaler_balanced.pkl", "wb") as f:
    pickle.dump(scaler, f)

# ==========================================================
# 9️⃣ Convert ke TensorFlow Lite
# ==========================================================
converter = tf.lite.TFLiteConverter.from_keras_model(model)
converter.optimizations = [tf.lite.Optimize.DEFAULT]
tflite_model = converter.convert()

with open("smart_farming_model_balanced.tflite", "wb") as f:
    f.write(tflite_model)

print("\n✅ Model TensorFlow Lite (Balanced) + Visualisasi telah berjaya disimpan!")
```

APPENDIX D
SAMPLE APPENDIX 4

PROTOTYPE PROJECT



CIRCUIT DESIGN



APPENDIX E
SAMPLE APPENDIX 5

1. CHAPTER 1 INTRODUCTION

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2. CHAPTER 2 LITERATURE REVIEW

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