A Resource Efficient IoT-based Distributed Overhead Smart Irrigation System

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FINAL YEAR DESIGN PROJECT REPORT

This Report Presented in Partial Fulfillment of the Requirements forthe **Degree of Bachelor of Science in Computer Science and Engineering**

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APPROVAL

This Project titled **"A Resource Efficient IoT-based Distributed Overhead Smart Irrigation System"**, submitted by Md. Al Amin, ID No: **212-15-4230** to the Department of Computer Science and Engineering, Daffodil International University has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of B.Sc. in Computer Science and Engineering and approved as to its style and contents. The presentation has been held on **14 May, 2025.**

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DECLARATION

We hereby declare that this project has been done by us under the supervision of **Dr. MD Taimur Ahad, Associate Professor,** Department of Computer Science and Engineering, Daffodil International University. We also declare that neither this projectnor any part of this project has been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

This report presents an IoT development smart irrigation system technology that use for water management and energy saving in agriculture. The system works with ESP32 and multiple sensors, including soil moisture sensor, temperature sensor, humidity sensor, rain sensor, and Pir sensor that provide the data from land. A motor pump controlled by L298L motor driver also store data in SD module that collect the sensor value and the project get the energy source from 12v solar panel that make the system stable. The system has an OLED display that presents the system activities in agricultural environments. The IoT-based irrigation system connects with Firebase so that all the sensor data present in real-time also control the soil moisture value and plant categories by using web and mobile application. This irrigation system develops on IoT which works and controlled from anywhere so that user can get access to monitor and get the control to setting up the system any time anywhere. Developing a web and mobile application their user can select the plant categories and create the plant categories, also monitor the sensors real-time data and controls the moisture and motor any time. The methodology employed real-time data aquation, cloud integration and local store also automated decision making to make the project more optimize in irrigation. The conclusion demonstrates improve water saving and electricity saving cost efficiency and user friendly. Cloud base real-time data helps to monitor and control the system. Local data storage helps to collect or logged the data so that the data might not miss while poor connection or after losing network. The system is automated so that it makes the setup environment itself and controls the system automatically. It has Esp32 microcontroller that work with low power and built-in Wi-Fi so that the system works perfectly over Wi-Fi also it has external power source solar Panel and 12V power source that makes energy saving and work all days. This project focus on agriculture that works IoT-based irrigation system to reduce the cost and save the water also save the energy that is very challenging now a days. It delivers water only, when necessary, then automatically stop the water supply. By adding real-time monitoring system automated irrigation and give the plant actual water moisture that helps to grow up healthy.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

This chapter introduces the background, motivation, and objectives of the smart irrigation system project. It highlights the importance of automation in agriculture and sets the foundation for the subsequent chapters.

1.1 Introduction

The IoT based smart irrigation system aims to change conventional farming by integrating the IoT technology to creates an effective and automated irrigation method. This project focus on electricity saving and optimizing water use and saving by assuring the right amount of water plant receive based on real time soil-moisture data so that excess water does not fall on the plants and is not wasted. By applying an IoT-based irrigation system, the irrigation will be automated using the sensor readings, effective and reducing the dependency for manual intervention and creating the process more efficient.

Soil moisture, temperature, humidity, motor-pump, rain and animal detection will be monitored by the IoT device using various sensors. All the sensors are controlled by the microcontroller and make the decision using sensor data. The system board ESP32 reads the sensors data and monitor in the web and mobile app also display in OLED display, sensors data and information store in SD card module so that the data not loss while poor connection. This process allows for continuous tracking and control of soil and weather conditions for ensuring precise irrigation.

A key feature has of this system is customized web application, which basically used Firebase for the protocol to communicate with the system. In this web application user will be able to choose the plant category that which plant user wants to growing such as Rice, Guava or Lemon, the system will automatically adjust the irrigation system based on the plant specific moisture requirements.

Once the plant is chosen, the system will adjust the irrigation accordingly to confirm optimal growth while serve the water. Moreover, to reduce dependency on external power sources and enhance sustainability, a 30-watt solar panel applied on this system. This energy source helps to active the system for long term for uninterrupted operation. This approach makes the project eco-friendlier and more suitable for agriculture area.

This smart irrigation system goals to improve the efficiency of agriculture, reduce water waste by integrating IoT technology automation, and renewable solar energy. This approach provides a scalable solution for farmers and researchers. The system that is monitored by a web application and able to control irrigation remotely, makes it not only convenient but also highly effective in defense applications, where IoT system are critical for maintaining secure and suitable in agriculture practices.

1.2 Motivation

The main computational motivation for this project is to provide and accurate irrigation based on real-time sensor data and cloud-based technology Automating decisions is a challenge. Traditional irrigation methods are more time consuming and rely heavily in manual observation. It also makes water wasting and prevents healthy crop growth. Using shallow pump, they use desal that harmful for the soil and river and make air and water pollution. By applying the IoT-based irrigation system the crop growth healthy because the system monitoring the environment like soil moisture humidity temperature sensor this sensor are fully related with agriculture field. This project provides the accurate water for irrigation so that water not wasting and also have solar panel that produce the power electricity free, that's why it also makes energy saving and eco-friendly. The system combining with hardware and software based so that user can easily operate and monitor the system. The system stores the data in to SD card to do data logging and monitoring.

From a proposal we solve the problem by deploying the IoT-based smart irrigation system. This project is fully functional and automated so that it can make the decision itself. This IoT device fully functionable and easy to use for everyone. A web application is created with best UI implement and controls the sensor and condition with using web application. To make more flexible there used a mobile app that show the real-time data and connected with device using firebase. So overall it is the best irrigation IoT project that can change the agricultural industry and field.

1.3 Objectives

The IoT-based distributed overhead smart irrigation system is designed to optimize water consumption. It is implementing with IoT based on web application so that the system control by the website. This project uses ESP32 to enable Rail Time to monitor soil and weather conditions and uses multiple environmental sensors. The application allows the user to select their own crops so that the system can automatically carry out the plant category and provide irrigation accordingly. To save electricity, an additional 30-watt solar panel system has been used to keep the process running throughout the day and night. The key objectives of this of the project are:

- **Real-time Monitoring Soil-moisture and Environmental Conditions:**
  To collect all the data from soil moisture temperature humidity raindrop motor startup and object detection sensor and then analyze it using ESP32. To ensure the sensor data is stored in the ESP 32, an OLED display show the status that all the sensors' data are storing in the SD card module so that the data might not be lost.

- **Development of an IoT-based Automated Irrigation System:**
  To implementing a machine that adjusts the water flow depending on the different crop moisture level specification. To ensure the motor pump activated when water is needed, reduce the over-irrigation and water wastage.

- **Integrate the Firebase Protocol for Data Communication:**
  To communicate the IoT device Firebase protocol make it efficient, communicate with low-latency between the web application and the IoT device.
  To ensuring the data exchange between sensors is reliable, the cloud-based web interface and the ESP32.

- **Development of a Web & mobile Application user-friendly:**
  To make a user-friendly interface there design a customized web and

mobile application interface where user can select the crop for irrigation and adjust the irrigation settings automatically. To see the real-time sensor data and the land environment and system activities, there deployed a display.

- **Implementation of Solar-powered Energy Efficiency:**
  To utilize the system a solar deployed that is 30 watts to power the system and make ecofriendly. To recharge the battery by using solar panel system that make the longevity of battery.

- **Enhancing System Reliability and Storage:**
  To store the historical data to SD card so that it can apply machine learning to develop predictions and future improvement. To ensure the error handling in the mechanism for reliable performance in various environmental conditions.

The distributed overhead smart irrigation system will operate an advanced automatic system that helps to grow crops well and make decisions. Achieving these objects, it will optimize electricity and reduce water wastage, and save the planet against pollution.

1.4 Methodology

The methodology for this irrigation system was planned to combined both hardware and software components into a stable automated solution. The processing technique began with proper planning the architecture that identifying the necessary sensors, Esp32 programming board, motor control components, a power supply and a power source also cloud services. Hardware components soil moisture, temperature, humidity, rain and PIR sensors are attached with ESP32. Motor pump controlled from L298N motor driver and OLED display control for monitoring with the help of ESP32.

The ESP32 was programmable and controlled to collect real-time sensors data, display values on the OLED display also controlled the motor pump based on the soil moisture. To make IoT firebase database connected with ESP32 that send and receive the value. To make user friendly interface a web application and mobile application was deployed that helps to control the irrigation system.

To make all time system running there use a 12v 5A battery that provide the energy, it is able to run the system long time during electrical problem. To charge the battery there use a 30w solar panel that recharge the battery quickly. Finally, through the testing and calibrating where all the sensors read the value accurately. These steps reduce the water wastage and save electricity also ecofriendly.

1.5 Project Outcome

This project has several outcomes by deploying the irrigation system that makes important both practical and technical. One main key is the successfully automated irrigation that irrigate based on the real-time environment data. The soil moisture level detects accurately by using the system, also temperature, humidity, rainfall and PIR detect the system accurately. It automatically controlled the motor based on soil moisture and provide optimal water to crops. This project significantly reduces the water wastage and improves irrigation efficiency.

Another big outcome is the renewable energy, to make more reliable and performing there use a 12v 5A DC battery that works long time and provide accurate power to the system. A 30w solar panel deployed in this project to get free energy. Solar can charge the battery easily and helps to perform well. So, this feature improves the sustainability and affordable solution that make energy saving.

the technical perspective is the project establish the effective use of IoT technologies. Using IoT cloud platform and mobile or web interface so that user can monitor the system and manage the agricultural system. The firebase connection helps to take real-time data and store the data and monitoring from Esp32. To login there use the firebase authentication to ensure the security. The mobile application and we application provide the easy user interface to the user and tracking the environmental status. The project outcome commits to promoting the smart agriculture principal by using automation and decision making based on data to improve crop yields. It also represents the valuable of the learning IoT system design and embedded programming.

1.6 Organization of the Report

This project report is organized into several chapters and each addressing has a specific form of the project that provide a clear and extensive understanding of the development process and outcomes of this irrigation system.

- **Chapter 1: Introduction**
  Introduce the project using outlining the background, motivation, objective and methodology. It also discusses the expected outcome, scope, ho to the report is structured comprehensive.

- **Chapter 2: Background**
  This chapter presents the important background knowledge so that to understand the project. In this chapter there includes literature review an over view of similar application also related research work and application also including gap analysis and the summery of this project.

- **Chapter3: Research Methodology**
  This chapter require the project overview also system design to visible or present the architecture of the project. Also gives the functional and nonfunctional requirements that apply in this project requirement. Then the context diagram that present the diagram of the project. Also, dataflow and UI design that use in web and mobile application.

- **Chapter 4: Implementation and Results**
  This chapter coverup the environmental setup, testing process and evaluation of system performance also results and discussion.
- **Chapter 5: Standards, Impact, and Management**
  In this chapter discusses the compliance that relevant standards, societal and environmental impact also ethical aspects sustainability plan and project management also financial analysis.

- **Chapter 6: Conclusion and Future Work**
  This chapter recap the work completed and highlights the project limitations also outlines potential areas for the future development.

Chapter 2

Background

This chapter presents a review of existing smart irrigation technologies and related works. It provides a comparison that helps to identify gaps and justify the proposed system.

2.1 Introduction

In recent years, it is challenging to growing the crops in agriculture sector has faces due to climate change. Water shortage and the need for more efficient farming practice in agriculture field. At present traditional irrigation method are affect in Agri field, the results are overwatering or underwatering also leading to wastage resource crop yield reduced and increasing operational coset. The global demand of the food rising and natural resource are increasing limited. The need for sustainable farming and smart solution has become more urgent than ever.

Integrating of Internet of things (IoT) technology make the solution in agriculture. The IoT technology into agriculture has developed as a solution to address these challenges. IoT implement the real-time monitoring system, automated decision-making management of agricultural systems. Smart irrigation is a use of combining sensor that in particular uses, software and communication network platform optimize water usages and help to improve crop health. This system can intelligently work and determine how much and when to irrigate with the help of the environmental parameter such as the coil moisture sensor, temperature sensor, humidity sensor and rainfall by measuring.

This project focused on the development of an IoT-based smart irrigation system by using ESP32 microcontroller. The system deployed with various sensors including soil moisture, temperature, humidity and rain sensor. the motor will operate based on these sensors and turn on through L298N motor driver. An OLED display always display the real-time sensor activities and an SD card store the data in locally so that data might not loss in poor connection. Firebase real-time database monitors the sensor value and helps to visible in web and mobile application. A web app and mobile app helps to control the system and make it suitable for the crop. The system is powered by 12V 5A battery, charged the battery with 30W solar panel to perform the system continuously, making it suitable and remote farming application.

2.2 Literature Review

Ala'F [1] proposed a smart irrigation system that use IoT and Machine Learning. There system use ML to make the decision automatically and provide to the farmer. The sensors are they use are soil moisture, temperature, humidity, and pressure, to send the data wirelessly they use (LoRaWAN) that means long range wireless network. There system store the data in cloud so that they can use the data in ML to predict the irrigation. They apply a Machin learning, the algorithm (EWDO-LSSVM) improves the data accuracy for predicting the irrigation. Their predicting accuracy is 87.50% that is good prediction for their system.

Zhang [2] present an irrigation system that IoT and LoRa based. They use long range wireless network to make the system IoT and communicate with farmer. They developed the nodes and gateway and EC-IOT communicate and computing technology for the IoT device. They use STM32 MCU to utilize the system and use WH-101-L for communication that 4G module. To se the sensors value they use the MQTT protocol that is light and efficient. They use WeChat developer tool to make a mobile mini program that interacts with cloud via message.

Sadhu [3] innovate IoT based irrigation system that optimize water wastage while increasing crop and lowering operational expenses. They integrate network for real time sensor data. Also, the use the algorithm that make the decision based on the sensors. Their system is fully automated and low-cost and water wastage solution in agricultural area.

Belarbi [4] proposed matching learning technique-based irrigation system to make optimized in water usages. To predict the system, they use ET prediction in agricultural technologies. ET divert the diverse the dataset into soil and also remote sensing data. They highlight the irrigation system so that by using the ML the system can make optimize irrigation schedule depending on real time data input.

Zhang [5] present an irrigation that intelligent and automated IoT system. They use (VANETs) named vehicular ad-hoc networks for authenticate connectivity and data transfer protocol between devices. They deployed fuzzy routing algorithm and neural network for optimizing the irrigation system depending on real time sensor data. There system allows user to monitor and manage the irrigation system control through mobile devices and computers. They proposed a design that cost effective and portable also adaptable to several agricultural environments. They simulate their irrigation system and the outcome is their system not only enhance lifetime and power efficiency but also have security and key management compared with WSN-IoT and LEACH protocol.

Liu [6] proposed a low-cost irrigation system based on a fuzzy rule-based algorithm. They present an optimal irrigation method that ensure the efficient data transformation through a fuzzy-based mechanism. Their system also able to do remotely control and monitoring using mobile device. Their system designed intelligently and cost effectively also portable that can use in various agriculture areas. Their proposed method makes out perform with existing algorithm also include DLQR, SPIS and FWIS.

Obaideen [7] propose a sensory based irrigation systems with IoT based which is related to the Sustainable Development Goals (SDGs). They are focusing on secondary data collection process based on approximate design along with. They used a automated irrigation system that is important for proper irrigation and minimalizing water usage. Ther approach to monitor the sensor data so that the irrigation may optimize and suitable for farmer to understand the irrigation technique.

Ragab [8] represent an easy process irrigation system with IoT. They make the system that make decision and take a specific action to complete the irrigation process, depending on the parameter it makes the decision that should they do the irrigation or not. They represent another version where they use a rain sensor DHT22 sensor and soil-moisture sensor also a microcontroller. To make IoT they used MQTT broker so that the sensor data show in the web application.

Also, they used weather forecasting API to see the weather.

Nigam [9] proposed an IoT-based advanced irrigation system, which is efficient for farming and water conservation challenges. They argue that continuous soil condition monitoring is a major problem for the farmer and proposes an IoT-enabled mobile application to track environmental changes. The study introduces a process to store data is called cloud-based data storage, it remotely monitors soil parameters and receive alerts via SMS and email to farmers. a significant contribution to this work is the tabulation of field parameters on the cloud server, which optimizes resource management and increases the efficiency of farming.

Gaitan [10] proposed a system that takes the temperature and humidity and soil moisture data and provide advance analytics for irrigation system. The data transfer wirelessly and monitored, using AI for generating predictive recommendation. The data transmission is performed through wireless via WebSocket. There device connect to the application to see the climate condition and environmental status. It identifying trend and generate the report using artificial intelligence.

Al Mamun [11] proposed a IoT based irrigation system that develop by the solar power system. They use a 20W solar panel to run the system and give the power to process. They use Raspberry Pi 4 as a controller, run the pump and other sensor such as DHT22 sensor and moisture sensor. They also use ESP8266 to collect the data from sensor and used 12V battery to provide the power to the system. For the communication they used MQTT protocol to transfer the data to the application. The battery able to run the system only two hours. The deploy a web application using python Django framework and also use SQLite3 for the database. The system able to gives the real time data to the user.
Belarbi [12] research on irrigation system using machine learning technique to optimize the system. They focused on ET prediction and smart irrigation system. The ET prediction use from the collective dataset thar comes from the sensors like soil moisture and temperature also humidity sensor. There system is automated and controlled by the user. To optimize the irrigation system the use ML model so that the next irrigation able to predict the system.

Tefera [13] proposed a system that IoT based named smart irrigation system using machine learning algorithm. To store the data, they use soil moisture sensor, humidity sensor, temperature sensor and motor pump. There model improve the water saving process and optimize the irrigation system. They made the system and simulate the testing prototype for the environmental data collection and prediction.

Janakiraman [14] proposed a mobile based solution in agricultural irrigation system. They used raspberry Pi and the sensors such as soil moisture and temperature and humidity sensors so that the system can irrigate properly. They use raspberry Pi to enhance the system and perform the system well. Also, collect the data and monitoring the environment. They use CNN and RNN also ANN model algorithm for machine learning so that the motor activation works properly and irrigate the system when needed.

Saikia [15] they proposed the irrigation system that use in remote areas, focusing on IoT deployment. They deploy a analyze IoT applications and highlight the key technical and economic policy. Integrating the system in rural area where is the challenging part that they focused to solve. Also, they utilize the system that cover the environmental area where irrigation is a challenging. That make the proper effective and positive impact.

Olayaki [16] proposed the design and calibration for an automated irrigation system that built with the Arduino Uno and a micro pump and other sensors such as soil moisture, temperature, and humidity sensors. The system programmed with C++ and they focused on the system to improve irrigation efficiency with the help of delivering water to crops depending on real-time soil moisture data. They use the controller an Arduino Uno as the central controller also for monitoring continuously the soil through embedded sensors. The Arduino triggers the micro pump when moisture levels drop below a set threshold. The C++ program helps to make sure the accurate sensor is readings or not and response quickly also reliable operation for the irrigation. A solar-rechargeable battery provides the power to the system successfully and the system automated irrigation based on live soil and environmental data.

Sihombing [17] focuses on the development of a technology that have automated irrigation process that integrates soil moisture sensors and water pumps. They deploy a solar panel also solenoid valves and microcontrollers for the efficient and timely irrigation process. There methodology cover up the hardware and software-based development for properly integration where soil moisture sensors work properly with a microcontroller as a central control unit. There system is programable and able automatically the irrigation based on real-time soil moisture that reads to ensure the water is applied only when needed. They publish the results that the system able to reduce water wastage by 34.2% compared to the traditional irrigation process. Also, there system able to control irrigation remotely by the farmers through the Internet or mobile application.

Belghachi [18] proposed the key components of smart irrigation systems. Also include sensors, weather forecasting and data analytics, automation, and the use of AI to optimize irrigation system efficiency. There propose focused on the benefits of smart irrigation system, such as water saving, improved crop yields healthy, low cost, and greater sustainability. With the examples from precision agriculture and urban farming both. there paper also discusses the challenges like high costs and technical requirements also data management and connectivity issues in irrigation system. They also explore the future prediction using advanced AI models to improved sensors and renewable energy integration also supportive policies and emphasizing smart irrigation's crucial role in durable agriculture and global food security.

Sharan [19] proposed a system that integration of Internet of Things technologies with machine learning algorithms, particularly the K-Nearest Neighbors (KNN) algorithm, to improve automated crop identification and manage the irrigation system. By taking advantage, these systems can determine crop type such as corn, wheat, or rice—and calculate by sensors that monitor soil moisture, temperature, humidity, and total dissolved solids. They used Arduino UNO microcontrollers and Adafruit bridges to enables real-time data collection and precise irrigation system control without human intervention. This paper focused on the potential of IoT-based smart irrigation systems that improve agricultural efficiency and promote sustainable water use in farming practices.

Dele [20] proposed a recent study on smart irrigation that accentuation the role of automation for improving water management efficiency and crop performance. They focused how smart irrigation systems work with combine microcontrollers and sensors also automated water pumps for optimizing the irrigation system based on real-time environmental data. By deploying decision-making algorithms, these systems enable definite the site-specific watering and reducing both water usage and power consumption. there paper underscores the potential of smart irrigation technologies for promoting the sustainable agriculture by dilator resource efficiency and minimizing the environmental impact.

Abidin [21] proposed a Smart Irrigation System that integrates a renewable energy source to make water efficiency and reduce indoor heat caused by solar radiation. They make a system that combines hydroponic plant cultivation with a mechanism that water flow cycles water from rooftops for planting into storage tanks and also back to the roof. Solar panels store the energy during the day, while water helps to flow through turbines generates additional kinetic energy to help to run the operation during night. By reducing the indoor temperatures and ensuring continuous water conduction, the smart irrigation system reduces energy and water consumption both. There review paper highlights the system's application to research on renewable energy hydroponics and sustainable water management system.

Mishra [22] proposed an advance automated irrigation systems that designed to reduce the need for manual intervention in agricultural practices. By developing the sensors that monitor environmental condition such as humidity and temperature sensor, soil moisture sensor, and pH sensor. They used in system Arduino controllers for triggering the irrigation events automatically. The data that collected is transmitted to IoT platforms and enabling farmers to remotely monitor and control irrigation. An advanced method, including data preprocessing techniques such as DBO and renaming also feature selection using Chi-Square, and machine learning models like GA-CNN-BiGRU, BiGRU, and CNN-BiGRU, are reviewed. The GA-CNN-BiGRU model present the superior performance and demonstrating its potential for improving irrigation efficiency and agricultural productivity.

Mulyono [23] proposed a high predictive accuracy in plant growth model for irrigation system that results showing a Root Mean Square Error (RMSE) and a coefficient of determination (R^2). The innovation of the approach lies in its integration of real-time monitoring and automated adjustments for optimizing the plant health. There future research directions are incorporating additional environmental sensors and enriching datasets to improve model adaptability across different type of crops and conditions. These improvements have the potential to drive the development of more practical smart agriculture systems that ultimately improving efficiency and boosting agricultural productivity.

Tasayco [24] proposed a design and implement a prototype mechatronic system for greenhouse irrigation management by using a microcontroller-based on embedded system. There system combine with temperature and humidity sensors to monitor environmental conditions and make an automatically control a water pump. A mobile application displayed the sensors data via Bluetooth and allowing remote monitoring and control. The results exhibit that the prototype is functional and meets its objectives. They also proposed an improvement including extending the Bluetooth communication range and incorporating with a solar panel for making the system suitable for areas without access to electricity.

Hassan [25] presents a several cluster-based selection schemes that adaptations of the Stable Election Protocol and also Distributed Energy-Efficient Clustering. It designed to optimize energy consumption in agricultural sensor networks and field. These schemes partition in the field into smaller regions for reducing the energy usage between distant sensors and the sink. The performance analysis using metrics such as network throughput and stability also lifespan shows that the proposed schemes consistently outperform in conventional methods. In their proposed simulation results express that the SEP-based scheme extends network is lifetime by 38% and improves throughput by 56.6% while the DEEC-based scheme increases network lifetime by 60.5% and throughput by 65%. This research demonstrates the potential of these schemes for improving the energy efficiency and network longevity in heterogeneous WSNs and enhancing smart irrigation system performance.

Table 2.1: Summary of Literature Reviewed.

Author (s)	Year	Title	Methodology	Key Findings
Ala'F et al	(2025)	Environmental remote sensing and prediction model	Wind-driven optimization algorithm	Improved water usage efficiency by predicting environmental changes.
Zhang et al	(2025)	An Irrigation System for Farmland Based on LoRa and Edge Computing	Irrigation system using LoRa (Long Range) communication	Use of LoRa allowed for long-range data transmission
Sadhu et al	(2025)	Proposed an IoT-based smart irrigation system	microcontroller and sensors to monitor soil moisture	automating irrigation based on real-time data
Belarbi et al	(2025)	Optimizing Water Management in Agriculture	incorporate machine learning algorithms to predict and optimize water usage	highly effective in predicting water requirements
Zhang et al	(2025)	intelligent and automatic irrigation system with IoT	Vehicular Ad-hoc Networks (VANET)	provided robust security for data communication
Liu et al.	(2025)	Intelligent and automatic irrigation system using fuzzy	Fuzzy logic was used to handle the uncertainty and variability	enabled better adaptation to changing environmental conditions
Obaideen et al.	(2022)	smart irrigation systems using IoT	analyzing different sensor networks, communication protocols	concluded that IoT-based smart irrigation systems offer significant advantages in water conservation
Ragab et al.	(2022)	IoT-based smart irrigation system	development of an IoT-based irrigation system using sensors for real-time data	reduced water usage and increased crop yield
Nigam et al.	(2022)	Advanced Irrigation Solution based on IoT	advanced IoT-based irrigation solution	to optimized water usage, reduced wastage, and improved crop health

Gaitan et al.	(2025)	Integrating Artificial Intelligence into an Automated Irrigation System	predict irrigation needs based on sensor data	significant improvements in irrigation accuracy

2.2.1 Similar Applications

In recent years, there a lot of research on smart irrigation system. To improve the agriculture effective and mor simple to handle the process, several researchers are working on it to improve the healthy crop yield.

Ala'F et al. [1] implement an environmental remote based sensing and using the algorithm to predict the enhanced wind-driven optimization, the project improved the performance properly and make efficiency with the help of IoT-based irrigation systems. Their work represents the necessity of combining the environmental data into an optimization technique to save water use effectively. Similarly, Zhang et al. [2] proposed an IoT smart irrigation system based on LoRa and also edge computing for farmland. It presents the benefits of long-range connectivity and decentralized computing process in large-scale agricultural area.

Sadhu et al. [3] designed a smart irrigation system IoT-based focusing on automation and optimization also reducing manual labor principles which is also big reason to this project. El Younoussi and Belarbi [4] study in various approaches that make combine smart irrigation systems with the help of machine learning and demonstrate how to optimize water management and adapt to changing environmental conditions by predictive algorithms.

Zhang and Li [5] make an intelligent and automatic irrigation system based on IoT. the architecture featuring authentication on VANET, finding system security that is important but it's often overlooked aspect for the system. Liu et al. [6] employed a technology named fuzzy control technology in an IoT irrigation system. It offering an adaptive and an intelligent decision making and capable to improve irrigation accuracy.

2.2.2 Related Research

The inquiry of this existing research and literature related on smart irrigation systems confess a growing trend towards the deploy mentation of Internet of Things (IoT) technologies such as sensor networks and advanced data analytics for optimizing water usage in agriculture area. To research several studies and applications we got innovative ways for improving on irrigation efficiency and sustainability.

IoT-Based Smart Irrigation Systems

Most of the research studies have focused on IoT-based irrigation systems that do real-time monitoring and automation. For example, Sadhu et al. [3] present a method smart irrigation system using simple and basic IoT components to make the system automate water flow depending on soil moisture levels which aligns closely with the sensor-driven based automation in this project. These processes often used microcontrollers and sensors to make data acquisition with cloud or the local servers for doing processing and decision-making technique.

Machine Learning and AI in Irrigation

There has been a prominent area of study by incorporation of machine learning and artificial intelligence into irrigation systems. Belarbi and El Younoussi [4] proposed the use of machine learning algorithms in agriculture for optimizing water usage by predicting weather conditions and soil moisture levels also crop needs. This study highlights how predictive models, and AI could improve the irrigation systems by attempting to dynamic environmental factors. Moreover, Gaitan et al. [10] presented the conduct of AI for predicting on irrigation schedules based on historic and real-time data. An area where could be integrated into future iterations for the current system to developed its adaptability.

Long-Range Communication and Edge Computing

Another studies have represented how to communicate in long-range communication technologies such as LoRa that low latency communication can be used to transmit data over the large distances in the remote agricultural fields. Zhang et al. [2] mobilized the LoRa for communication in smart irrigation systems that reduces the dependency on local area networks and enhances the scalability and particularly in large farmlands. This study provides a substitute solution for remote monitoring system that could be investigated for expanding the current irrigation system's reach.

Energy-Efficient Solar-Powered Systems

Energy efficiency is also another important aspect for IoT-based irrigation systems moreover in off-grid or rural areas. The renewable energy sources which is solar panel is integration for powering irrigation systems that has been widely researched. Zhang and Li [5] published the benefit of solar-powered systems with IoT devices to make sure that irrigation systems work operational in areas with deceptive power grids. This concept presents the importance of solar panels where power sources are a challenging part.

Cloud Integration and Real-Time Monitoring

In the agriculture field cloud integration is the source of developing the sector areas. Most of the researchers use cloud integration for their research and applied it to irrigation systems. Getting real-time data that my loss in some other reason can store in cloud so that the data may not loss anymore. By using cloud integration, it is easy to monitor the real time data and use machine learning and artificial intelligence.

2.3 Gap Analysis

In presenting research, there have been several important gaps that are necessary in this project irrigation system. Where all the researchers integrate the basic solutions in agriculture such as soil moisture and humidity and temperature sensors, but they do not add rain sensors that can automatically irrigate the soil. So that is a lack of other research contributions. During rainfall the system does not detect rainfall and irrigate continuously that may waste a lot of water. Also, the other researcher presented the system that directly dependent on electricity but does not generate electricity itself. To reduce this lack our system uses the solar panel that charges the system's power source so that it works perfectly without any external or dependent power source.

Another notable lack is to store the data in local storage that is important when the connective is poor and cannot send the sensors data in cloud storage. Our proposed project solves this problem where our system stores the data locally into the SD card so that the data may not be lost when the connectivity is poor. Also, we use the firebase real-time data and database so that it stores the data in display the data in online connection or network.

We found another lack in the review research paper that is the plant category selection. So, it is very important to manage the plant category so that any type of plant can be used by this system properly. Other researchers implement the system statically like their system has no changes functionally.

Table 2.2: Gap Analysis

Features	Existing System	Deploy the Existing system	Proposed system
Real time soil moisture monitoring	Yes	Yes	Yes
Real time soil moisture monitoring	Yes	Yes	Yes
Rain detects for irrigation control	NO	Yes	Yes
Automated motor control based on moisture	Yes	Yes	Yes
Solar power system for power source	NO	NO	Yes
Firebase real time irrigation Database	NO	NO	Yes
Web app motor sensor data monitoring	NO	Yes	Yes
Mobile app for control and monitoring data	NO	NO	Yes
Email password for the security	NO	NO	Yes
Plant category management	NO	Yes	Yes
Automaton and manual shipment	NO	Yes	Yes

2.4 Summary

After researching and reviewing the agriculture smart irrigation system, we found several solution and related work of our proposed project irrigation system. The similarities are the sensors that our proposed project has deployed and perform the system. Also, we found the lac of the system by reviewing the several research paper such they do not deploy that rain sensor that very important in agricultural field. To use the rain sensor there a big change to reduce the water wastages and save electricity both. It is important the system should turn off or the function stop the task while raining. Another significant gap that we discovered is the local storage in the irrigation system. Most of the researcher use the cloud-based monitoring system but it doesn't work while the poor connectivity or loss the network. To fill this gap, we deploy the local storage using SD card module so that after loss the connectivity it performs continuously and store the data in locally. this section also presents the gap analysis where all the gaps that did not fulfil the process before for example rain detected based irrigation control, solar power system, firebase communication system, web application and mobile application. In this project this gap analysis is more important to complete this irrigation system. After that all the gaps are fill in propose system section. Also explain the related research where several researchers proposed the different type of irrigation system.

Chapter 3

Research Methodology

This chapter explains the overall methodology used in designing the smart irrigation system. It details the hardware components, software tools, and design approach adopted for implementation.

3.1 Methodology & Design Specification

3.1.1 Overview

The methodology for this project is to focus on design and developing the IoT based smart irrigation system. Thes project integrates the hardware components and cloud services also software application to make an automated, efficient and suitable solution for agricultural irrigation.in this project the system was designed through carefully requirement analysis, hardware, software integration and component selection and testing to confirmed the project objective. The core of the system is the microcontroller ESP32, it chosen because it has bulti in WIFI and Bluetooth module. It is capable to low latency connectivity and send and receive the sensor data in other applications. It helps to connect with firebase database to display real time data in a web application and mobile application. The system integrated with several sensors such as moisture, temperature, humidity, rainfall, and PIR sensor to monitor the agricultural environment continuously. A motor pump connected with a L298N motor driver that gives the current power to the motor and controlled by the ESP32. It helps to ensure the crops are watered efficiently without human intervention. The system powered by the 12V 5A DC battery that enough to provide the power and connect with 30W solar panel to charge the battery efficiently. Al so integrates a solar controller for the supplying accurate power to the system. The OLED display shows the real time data and environment activities for the user convenience. This chapter provides and overview for the requirement analysis and design specification. The software architecture subsists of firmware programmed into ESP32 board. Firebase database backend uses for data store and monitors and both web and mobile application make it user friendly to the users. In web app and mobile app there need to login with firebase authentication for extra security purpose.

3.1.2 Proposed Methodology

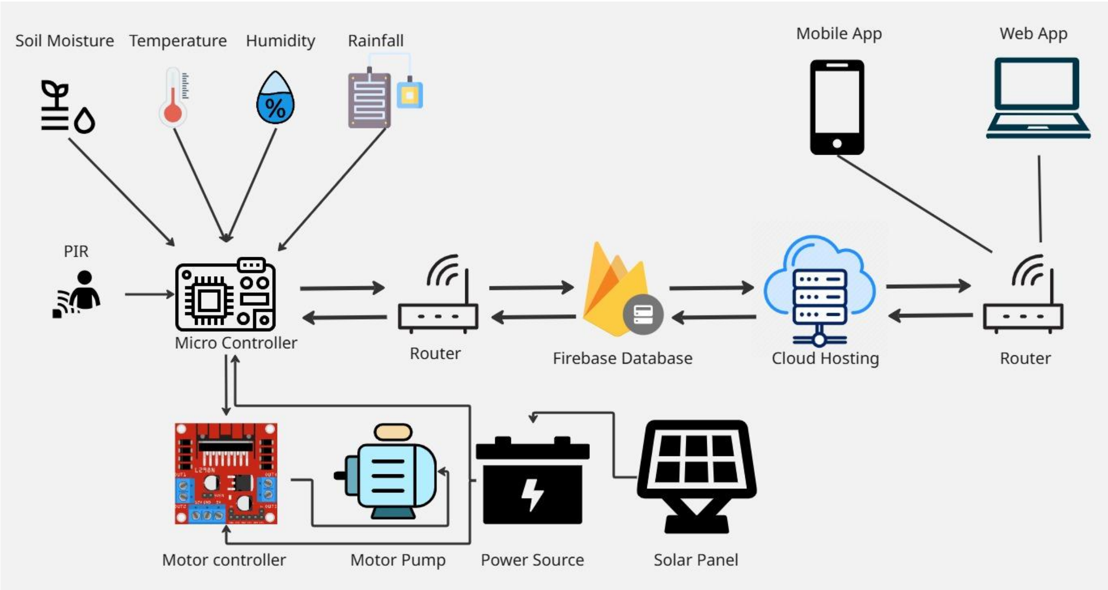

Figure 3.1: The Methodological Procedure

In this methodology there we represent the full process of our project irrigation system. To control the system and automated irrigation system we use EP32 microcontroller and sensors such as temperature, humidity, soil moisture, rainfall and PIR sensors. Also add a motor pump to do irrigation. These equipment's are the initially for the irrigation process. When rainfall that time motor will stop.

To control the system, we use web application and mobile application to operate the system. The user interface is secured with firebase authentication system also there shows all the equipment's current status. User can create plant and add it to the dashboard also user can delete or remove the plant based on their requirement. It has a function to make the irrigation system automated and manual. Also add the function to pause the real-time irrigation system.

To make the system IoT based real time irrigation system we deploy a database server by using Firebase database. It is easy to use and easily handle the system with free of cost. Firebase also support to hosting the web application and mobile application. So, for that reason it is beneficial for this project.

To provide the energy we integrate a 12V 5A battery to run the system long time also for recharging the battery we integrate a 30W solar panel that suits for this battery. Also add an OLED display to see the operations in agricultural area. Also add a SD card module to store the data in CSV file so that data may not loss.

In this project we use HTML, CSS and JavaScript for web application and also use MIT app inventor for the mobile application. To compile and upload the code into ESP32 we use C++ and Arduino IDE with requirement libraries.

3.1.3 System Design

The propose system design is made for smart irrigation system project that integrate multiple hardware and component, sensors like soil moisture, temperature, humidity, rainfall and PIR.

Also cloud service and software applications make it automated the irrigation process efficiently and sustainability. In this project, the main goal is to monitor the environmental conditions in real time and control the irrigation motor automatically by ensuring the optimal water usages while providing remote access and monitoring through the web and mobile applications.

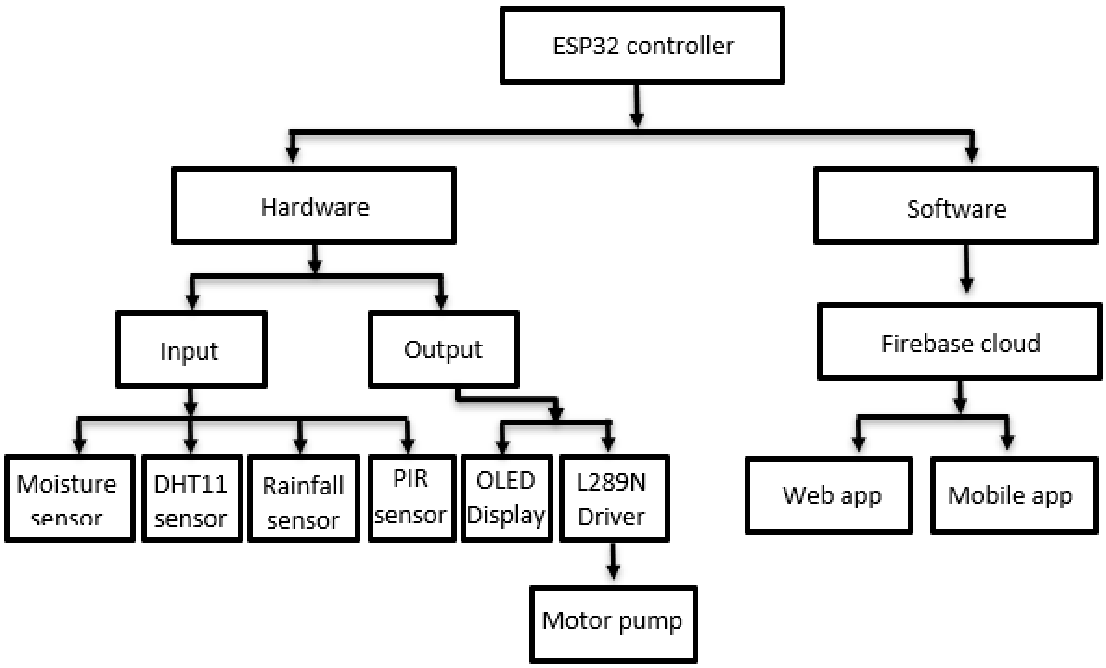

Figure 3.2: This is an irrigation system work flow

3.1.4 Functional and Nonfunctional Requirements

1. **Functional requirement**
   - **Soil moisture monitoring:**
     The system must monitor and measure the soil moisture level using soil moisture sensor.
   - **Temperature and Humidity Monitoring:**
     The system monitors the environmental temperature and humidity using DHT11 for crop.
   - **Rain Detection:**
     System always detects the rainfall so that when it's raining that time motor pump will be off and reduce water wastage.
   - **Automated Motor Control:**
     The ESP32 control the moto to make automated irrigation system based on the other sensors in the environment, when moisture is low then motor will turn on, when moisture is high then motor will turn off.
   - **Data Logging to Firebase and SD card:**
     Data that receive from the sensor is logged into SD card local storage and also cloud based firebase storage that helps to see the data in web and mobile app.
   - **Display Real-Time Data Locally**:
     The OLED display present the real time data locally to se the data without any connectivity.
   - **User Authentication:**
     The mobile and web application must login to run the software and for access the system management. There uses firebase authentication process.
   - **Real-Time Data Visualization:**
     The mobile and web application always display the real time sensor data, motor status, and able to control monitor field condition remotely.
   - **Plant Category Management**
     User can able to create plant also select plant and delete plant based on user choice. Every plant has a different threshold to get irrigation properly.
2. **Nonfunctional Requirement**
   - **Reliability**:
     The system operates continuously and reliably especially in agricultural environments and fields where stable performance is critical to handle.

- **Energy Efficiency:**

  In this project, the system must use low power consume components and powered by the solar panel that makes the system more stable.
- **Scalability:**

  The system designed in a modular so that the system may add more sensor or components in future.
- **Usability:**

  The web and mobile application are a useful thing for this project. User can customize the system and monitor the system also it is user friendly UI with minimal technical experience.
- **Security:**

  User data and access also be protected using firebase authentication and secure data.
- **Maintainability:**

  The system codebase setup must be easy to upload and hardware-based setup also. If there need to implement a new component then it is possible to add.

3.1.5 Context Diagram

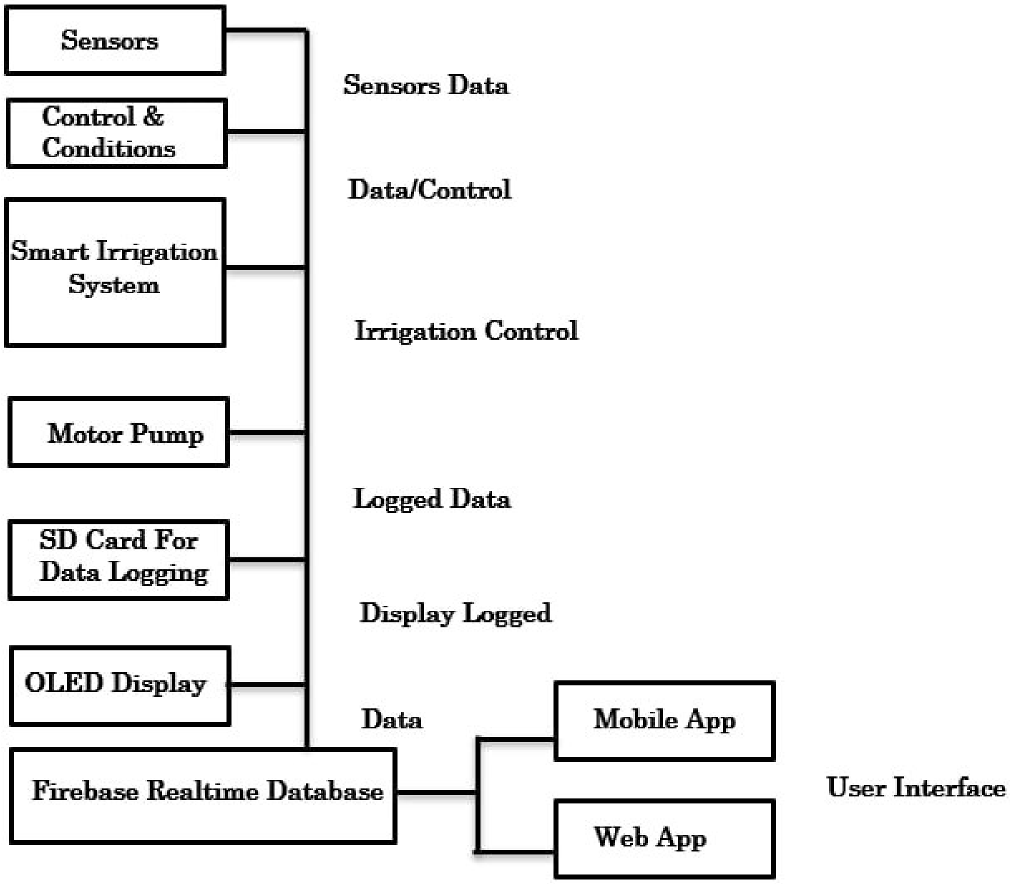

Figure 3.3: This is an irrigation system context diagram

The context diagram that represents in this section is the complete architecture of a smart irrigation system that developed as part of a research-based thesis project. It represents reduce water wastage usage and remote monitoring system. The system begins with a default of environmental sensors that continuously store data such as soil moisture, temperature, humidity, rainfall, and motion detection. This main sensor data is transmitted to the Control and Conditions module to processes the inputs based on pre-set threshold values for making the real-time decisions. If irrigation is required to control signals are sent to the Smart Irrigation System that is in turn activates the motor pump to water the crops. Simultaneously, all the sensors reading and system actions are logged into an SD card module when the system in offline. To make sure that the data availability even without internet connectivity. An OLED display is used for showing live readings and system status to the users on-site. For remote access and user interaction, the Firebase Realtime Database serves used as a cloud-based platform where data is continuously updated. This enables both a mobile app and a web app to fetch real-time and historical data, giving users full control and visibility over their irrigation system from any location. The entire system is designed to be automated, energy-efficient, and user-friendly, promoting sustainable agricultural practices.

3.1.6 Data Flow Diagram Level 1

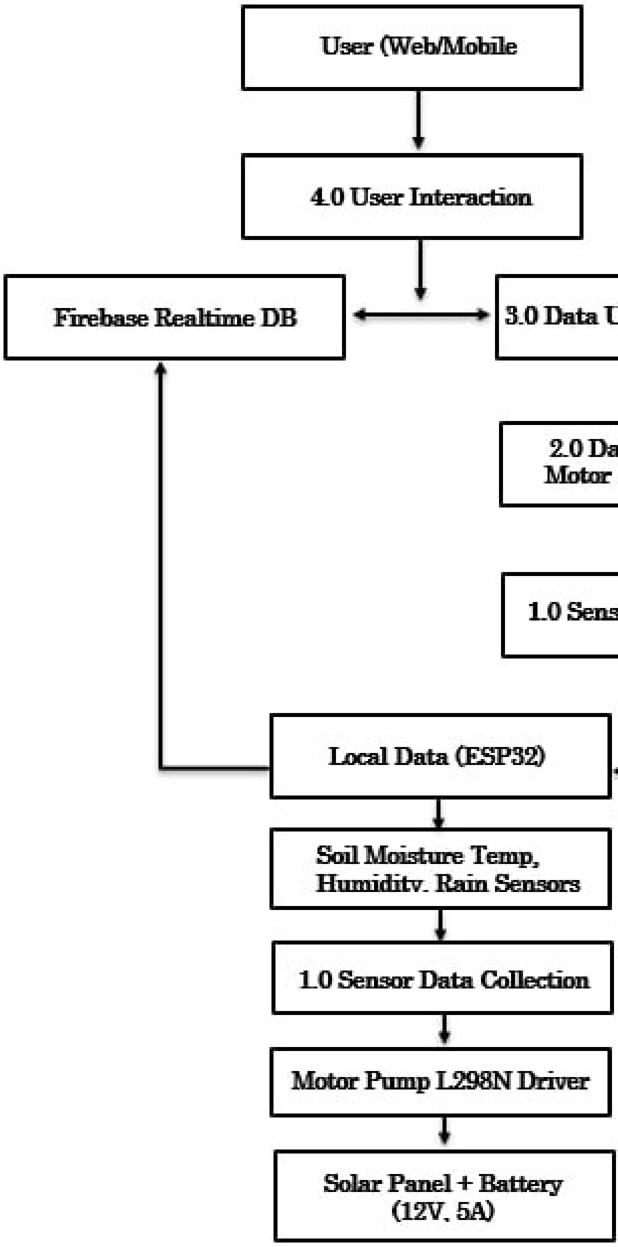

Figure 3.4: This is Data flow diagram level 1

This section we represent the architecture and operational flow of a smart irrigation system developed for research purposes. At the core of this system, there is the ESP32 microcontroller which performs the critical tasks using sensors data. Also, data processing and motor pump control handle this controller. The system runs by collecting environmental data through various sensors including soil moisture, temperature, humidity, and rain sensors. This core data is first processed locally by the ESP32 which makes the real-time decisions regarding irrigation based on predefined thresholds.

The motor pump, controlled through the L298N driver that is powered by a renewable energy source consisting of a 12V 5A solar panel and battery setup. To make sure the energy efficiency and sustainability in remote or off-grid agricultural areas.

The ESP32 also uploads the sensor data to the Firebase Realtime Database that acts as a cloud storage and communication medium. This enables real-time synchronization between the hardware and the user interface. Users can get the access, either through a web or mobile application that can interact with the system by monitoring live sensor values and control the irrigation pump manually if needed. This interaction is reflected in the Firebase database and fed back into the ESP32 for immediate action. Overall, the system offers a reliable, autonomous, and energy-efficient approach to modern irrigation practices, reducing human effort and conserving water through smart decision-making and real-time control.

3.1.7 UI Design

The UI design is made for better user interface experience and control the system we make two UI interface web app and mobile app. Both user interface is same and suit on both. we will present the mobile app and web app. In this project UI is the most important element. By deploying the user interface user can control the motor by using web user interface. We integrate several buttons with different operations. User can create plant category by pressing the add plant function. Also, user can select the created plants so that it did not need to create again. Also, in web user interface there add a delete function so that user can delete or remove the plant if farmers doesn't want to plant anymore. Also, in this project there have a switch that make the system automated to manual when user select the irrigation system to irrigate manually. There have also login and signup option to verify the account. It's very important for the irrigation system for security purpose.

3.2 Detailed Methodology and Design

A resource efficient IoT based distributed overhead smart irrigation system is developed for automated and efficient irrigation. Using Esp32 to communicate each other with different method, sensors reading and send data to ESP32 to store the multiple environmental information. The design aimed on embedded system and a web-based application, gathering real-time sensors data and monitoring, command and controlled by Firebase real time database communication protocol to make it professional and user friendly.

In developing the irrigation system, it tested and planned with the necessary of this project that this project is very useful and important. We focused to create an efficient, cost-effective and stable system that capable to monitoring and irrigation the agricultural environment.

- **Manual Irrigation System**

  In this approach, most of the farmer do irrigation manually or gardeners after observing and monitoring the soil conditions or weather condition.

  Reason for rejection:

  By irrigate manually, its wastage the water that can do irrigation in nest step. Also, manual irrigation may damage the crop yield and increase the financial cost for the observation.

- **Timer based Automated Irrigation**

  This smart irrigation system does irrigation until the soil goes wet or enough for the crop.

  Reason to rejection:

  Timer based irrigation system do not consider the real time environmental conditions such as soil moisture measure, rainfall detect or temperature. that reason it led the overwatering or underwatering also waystage water during rainfall.

3.2.1 Proposed Hardware Setup

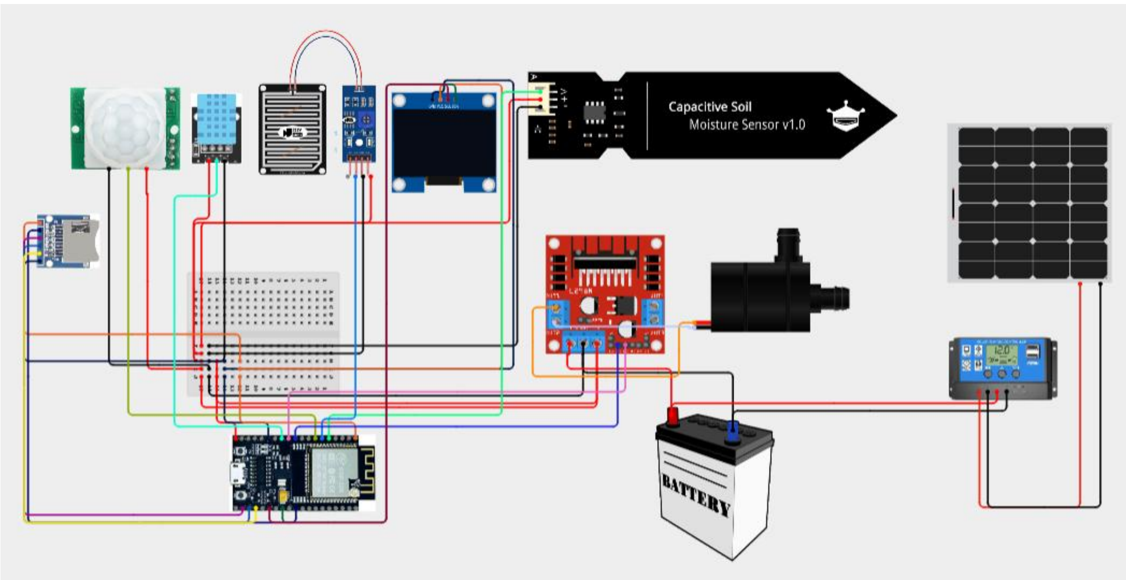

Figure 3.5: Circuit Diagram

From given diagram that shows the methodological procedure where 30W solar panel connected to the 12V DC battery. The Battery connected with microcontroller and motor controller. To connect the battery with ESP32 there use a voltage regulator so that the controller does not damage for over voltage. Then the ESP32 microcontroller read the sensors data like soil moisture and temperature, humidity, PIR sensor and rain sensor. The soil sensor reads the soil moisture and DHT11 reads the temperature and Humidity also Pir sensor detects the animal. When rain detect the sensor that time the Motor automatically turn off on the other hand when soil moisture is low that time microcontroller enables the motor controller to turn on the motor. ESP32 connect to the internet through the Wi-Fi and connect to the Firebase Database. This Firebase database collect the data and gives the real time data. To send the real time data firebase connected with cloud hosting that helps to run the web application and mobile application. After that user can see the real-time data using web app and mobile app. And control the irrigation system easily. Also there have an SD card module that store the data locally and an OLED display that connected to the ESP32 for showing the environmental activity.

3.2.2 Proposed Software and Web Application Setup

The software and web application setup of the proposed IoT-based Smart Irrigation System is designed to ensure efficient data communication, user interaction, and remote control of the irrigation process. The software component includes the embedded firmware programmed into the ESP32 microcontroller using Arduino IDE with C++ language. This firmware is responsible for collecting real-time data from environmental sensors such as soil moisture, temperature, humidity, raindrop, and PIR sensors. The ESP32 then transmits this data to the Firebase Realtime Database using Wi-Fi connectivity. Firebase was selected as the cloud backend due to its real-time synchronization capabilities, free tier usage, and built-in features such as authentication, database management, and cloud hosting.

For the front-end development, a responsive web application was developed using standard web technologies including HTML for structure, CSS for styling, and JavaScript for interactivity. This web application allows users to log in securely using Firebase Authentication and access a user-friendly dashboard where real-time sensor data is displayed. Users can monitor soil and weather conditions, control the irrigation system manually, and manage plant categories with ease.

The web app also includes features to switch between automatic and manual modes,

pause the real-time data flow, and create or delete plant profiles based on their irrigation needs.
Additionally, a mobile application was developed using MIT App Inventor, a block-based visual programming platform that allows rapid Android app development. The mobile app mirrors the functionality of the web application, providing farmers and users the flexibility to monitor and control the system remotely using their smartphones. Both applications fetch and display data from Firebase in real time, ensuring seamless interaction and continuous monitoring of agricultural conditions. This integrated software architecture enhances the system's usability, accessibility, and performance in real-time smart farming environments.

3.3 Project Plan

This section is the structured project plan followed for the design, development and implementation for the smart irrigation system. To identify the problem on agricultural field then the water wastage problem and electricity saving that is very important to solve in the agricultural field. We use the Esp32 for making and deploying the project that handle all the process of the project. There designs the structure of this project so that is may easy to deploy the project and save the time and reduce the financial problem. To design the project there use OLED display to see the real time data and environmental activity so that after the poor connectivity user can see the system working or not. Also, ESP32 has a built in WIFI.

It helps to connect to the device in to IoT platform. Hardware is the main component to build the project fulfil. In hardware sanction we use motor Esp32 Pir sensor moisture sensor OLED display Raindrop sensor solar panel battery and wires. After deploying the hardware component in this project, we deployed the software to control the system without coding and testing. For database we use the firebase database because it has built in database structure and optimize for the IoT project. We make web application and mobile application to view a user interface. We test the project hardware and software both. we find the solution to make it easy to use. Then we fixed the bug issue of the code section and testing the code is working well. After that we connect the web application with firebase database backend to connect the device properly. To check that the project working or not and the system perform well or not then we attach the device with firebase and also connect the mobile app and we app with fire base. Then test it the system function work perfectly or not.

3.4 Task Allocation

The task allocation is essential for testing the project deployed properly and the software and hardware work properly. To maintain smooth, perform. There need to connect and program the after all we have done the project successfully. These all the tasks done by me with the help of some instruction of the internet.

In order to carry out the project effectively, I divided the overall work into smaller, manageable tasks involving both hardware integration and software development. The initial task was to gather and interface all necessary sensors, such as soil moisture, temperature, humidity, rain, and motion sensors, with the ESP32 microcontroller. I programmed the microcontroller to collect data from these sensors and process the readings in real time. After achieving successful data acquisition, the next task was to implement control logic for the smart irrigation system, which included configuring threshold values and automating motor pump activation when soil moisture dropped below a certain level.

Simultaneously, I set up the SD card module to store data logs in CSV format with timestamps, and integrated an OLED display to visualize the sensor data instantly. Additionally, I configured the Firebase Realtime Database to upload sensor readings and motor status to the cloud, enabling remote access through both a web and mobile interface. Programming the interface to synchronize with Firebase and reflect real-time updates was another critical task. Throughout the project, I conducted multiple rounds of testing and debugging to ensure reliable communication between hardware components and cloud services. All these tasks were carried out independently by me, relying heavily on online documentation, tutorials, and community forums for guidance. This structured task allocation and problem-solving approach contributed significantly to the successful completion of the smart irrigation system.

3.5 Summary

This section provides a full detail overview of the project that starting to initialize the project. In this chapter we discuss the project methodology, requirements, software and hardware deployment process. The architecture work flow and circuit design progress. we also discuss the problem and the solution by implementing the project and working process and solve the irrigation problem solution. This chapter begins by outlining how the project was initiated, including the identification of the main objectives, scope, and expected outcomes. It highlights the importance of defining the system requirements clearly before starting the development process. The methodology adopted combines both hardware and software development approaches in a structured manner to ensure accuracy and efficiency. Various components such as soil moisture sensors, DHT11, rain sensor, PIR sensor, and motor drivers were selected and integrated with the ESP32 microcontroller to collect data and control irrigation accordingly.

A detailed explanation of the software deployment process is also included, covering Arduino IDE programming, Firebase integration, and SD card data logging. The Firebase Realtime Database plays a key role in storing and synchronizing sensor data and control commands, enabling remote access via a web app. The architecture workflow shows how data flows from sensors to microcontroller, and from there to local and cloud storage. Circuit design was carefully planned and tested to avoid malfunctions, ensuring that all components communicated reliably.

Additionally, the chapter discusses problems encountered during system integration, such as incorrect sensor readings, communication delays, and power supply issues. Solutions were proposed and implemented effectively, resulting in a functional and efficient smart irrigation system. The use of real-time monitoring and data logging provides valuable insights for better water management. This chapter plays a crucial role in demonstrating the successful implementation of the system and how it addresses irrigation issues in a smart and automated manner.

Chapter 4

Implementation and Results

This chapter describes the practical implementation of the system, including integration of sensors, Firebase, and the SD card module. It also explains how the project was developed and tested.

4.1 Environment Setup

The environment setup for the irrigation system is prepared both the hardware and software. The requirement hardware and software ate tested with the working place and make the project complete and user friendly.

Hardware Environment Setup:

Microcontroller:

Esp32 is the selected board that capable and able to handle all the task. It has built in Wi-Fi and Bluetooth support. Also, it takes low energy to operate the system

Sensors and Actuators:

- Soil moisture sensor
- DHT11 temperature and humidity sensor
- Rain detects sensor module
- Motor pump
- L298N motor driver
- OLED display

Power Supply

To power the system, we use 12v 5A battery that enough to give the energy every hardware component. To chare the battery we use a 30W solar panel that takes 2-3 hour to charge the battery.

Software Environment Setup:

Firmware Development

The ESP32 is a programable board that do program in Arduino IDE, it's free to use and opensource software. It is easy to use and coding and uploading easily and automated library installed support. All the required libraries for this project are installed from Arduino IDE.

Cloud Performs

We use firebase database to make the project IoT. It easy to use and it makes the backend program automatically it is free for real time database and hosting the web application.

Web Development

To make the web application we build the frontend. To make frontend user interface there use HTML for structure CSS for style and design and java script for make the page functional. Also connect the firebase by using the API and secret id also for communication and send the message we use message id.

Mobile app Development

To make a mobile app we use the MIT app Inventor that online based platform where android app can make easily. After making the app it generates the function and blocks then provide a perfect mobile app.

4.2 Testing and Evaluation and Performance Analysis

4.2.1 Testing Environment

Hardware Testing

Each sensor like soil moisture, temperature, humidity, rain sensor was tested individually by the Arduino IDE Serial Monitor for verifying the accurate data collection. The L298N motor driver and motor pump were tested to ensure the proper switching based on sensor thresholds. To ensure real-time display of sensor readings the OLED display was checked also.

Software Testing

The ESP32 firmware tested to ensure the communication with Firebase Realtime Database smoothly. Web and mobile applications were tested on different devices and browsers to check the real-time data display or not also check the smooth navigation and correct user authentication.

System Integration Testing

Once hardware and software components were perfectly integrated then entering the system on tested in several environment. the main focus on automatic motor control, rain detection shutdown and data synchronization by Firebase.

Battery and Solar Testing

The 12V 5Abattery and for charging 30W solar panel were monitored to assess charging efficiency and power supply stability, so that the project overall energy sustainability during day and night cycles.

4.2.2 Performance Analysis

Sensor Accuracy

The soil moisture sensor showed the accurate soil moisture and the average error is 5%. The temperature and humidity sensor reliably measured temperature and humidity but it takes the data around its area.

System Responsiveness

System responded within 1 to 2 seconds to change the moisture value and rain detection for ensuring timely motor control. Firebase updates the data that near real-time and response with minimal latency in the web and mobile applications.

Power Efficiency

The power source setup successfully and maintained the system operation during daylight and solar help to stored sufficient charge for night use for making the system energy efficient and cost free for the user.

4.3 Results and Discussion

The Smart Irrigation System was deployed and develop successfully. Through a series of tests in both controlled and real-world environments its performance was evaluated successfully. This section describes the key results and provides a discussion of their significance irrigation system.

Sensor Performance

The soil moisture sensor detected dry and wet soil conditions accurately also consistently, when moisture levels fell below the set threshold it triggered the motor pump. To measure the temperature and humidity DHT11 sensor is the best for that. The rain sensor detected rainfall and give command to disable the irrigation system when needed.

Motor and Pump Control

The motor pump properly controlled by the L298N motor driver. It operated automatically and smoothly based on real-time sensor readings data. When the soil was dry the motor turned on and when sufficient moisture was detected then turned off the motor also when rain was present that time motor automatically turns off.

Power System

The 12V battery get the energy or charged using the 30W solar panel. It able to powered the system throughout the day and night successfully.

Firebase Integration

The Firebase real time Database was successfully receiving the data from sensor, where it updated in real time data. The web and mobile applications able to display the sensor values accurately and allow to users to monitor conditions remotely. Firebase Authentication worked perfectly. It also makes ensure that only registered users can get could log in.

User Interface

The web and mobile apps provided a clean user interface and gives user friendly experience. Users were able to view and monitor the sensor data that helps to manage plant categories.

Login Page

The login page is simple and standard, but it has security and need to sign up for the account to get the access of this irrigation system. It has firebase authentication integrated to ensure secure login. Also, it shows error message for login with incorrect credential.

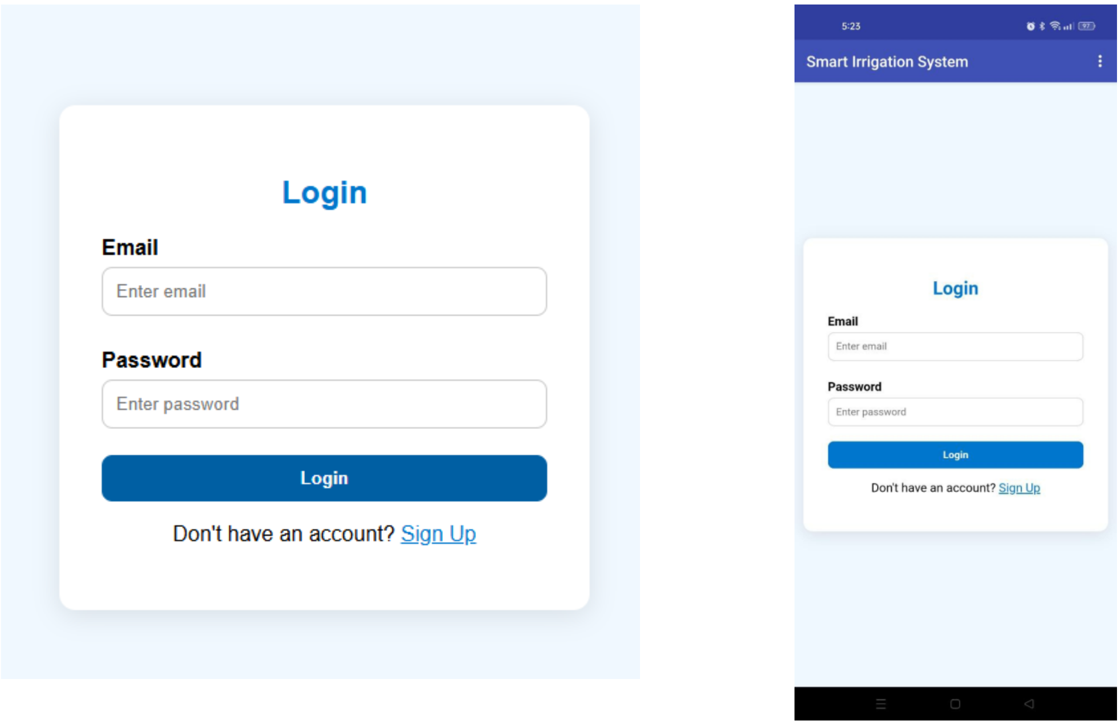

Figure 4.1: Login Page

Dashboard

In dashboard there show all the sensors data and activities. There has plant category option to select plant category also have create plant where user can create plant for the irrigation. In this application there have also a delete plant option where created plant information can remove from database. Also, it has the functionality to switch the irrigation process on or off. At the last there have a logout button to close the application. In dashboard there have two graph chart that show the history of soil moisture and humidity.

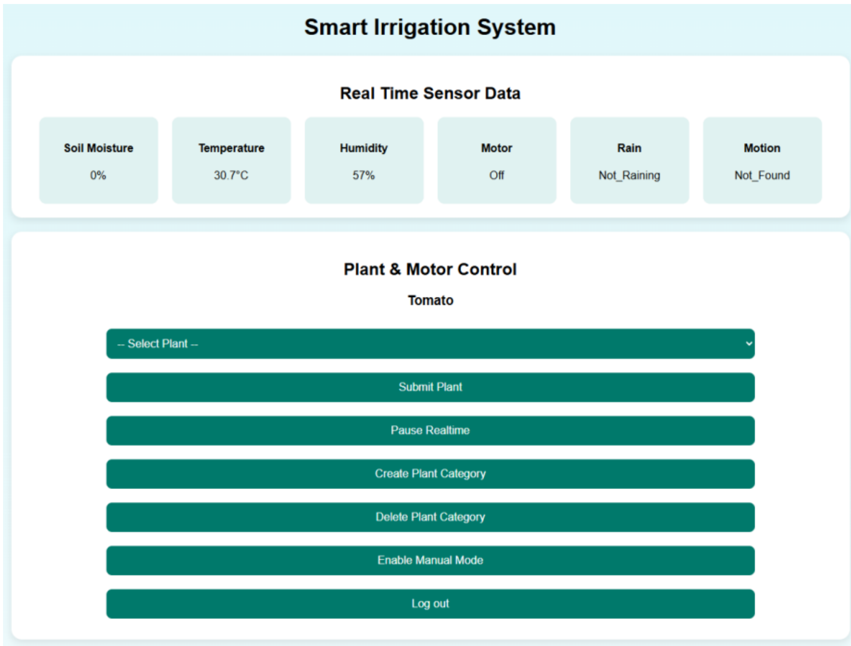

Figure 4.2: Dashboard Web App

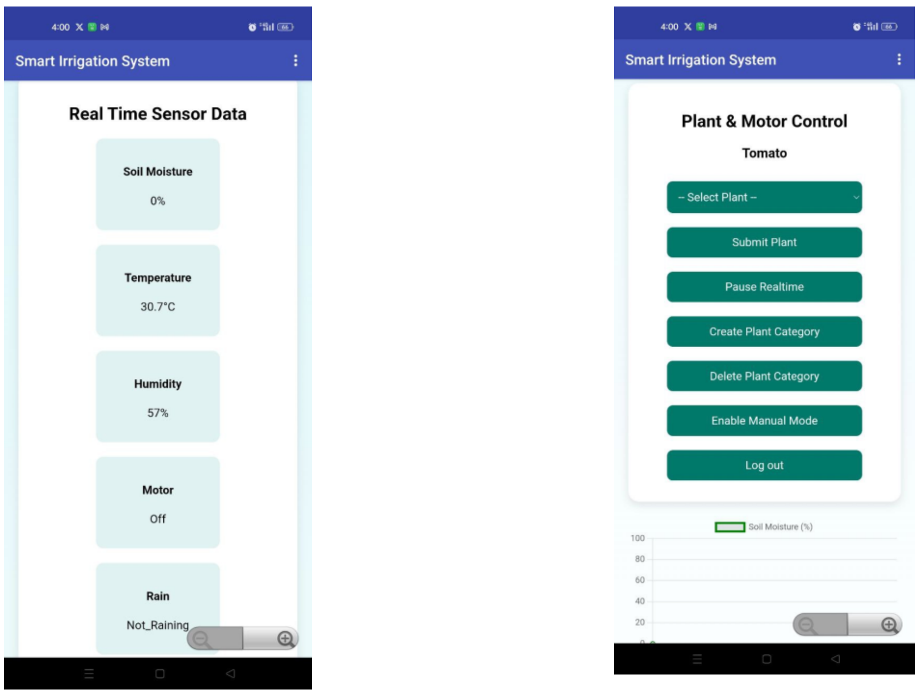

Figure 4.3: Dashboard Mobile App

Plant Management or Create Plant Category

In plant category page there have plant name where user input the plant name. it has minimum moisture and maximum moisture to manage the plant requirements. After submit the add plant then it goes to the dash board and present the plant category.

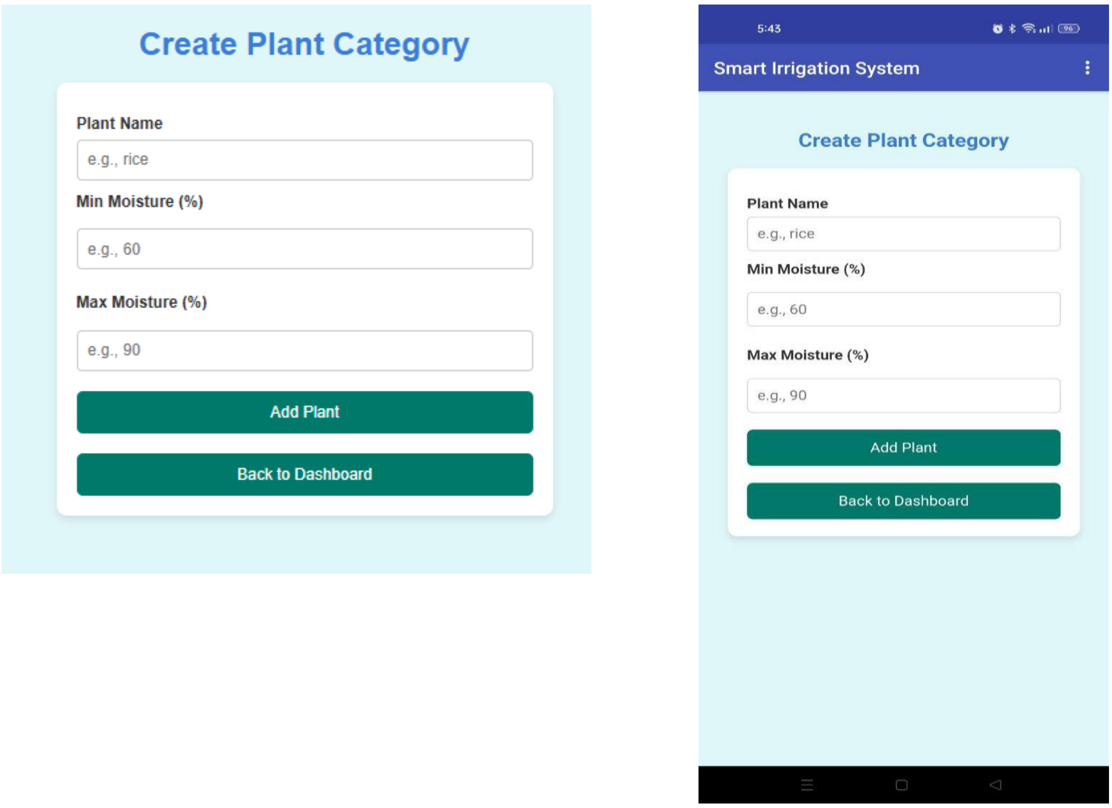

Figure 4.4: Create Plant Page

Delete Plant Category

In this section their user can delete the plant from firebase and cleat the unwanted plan categories. Also, user can see the existing plant that are used in the irrigation system.

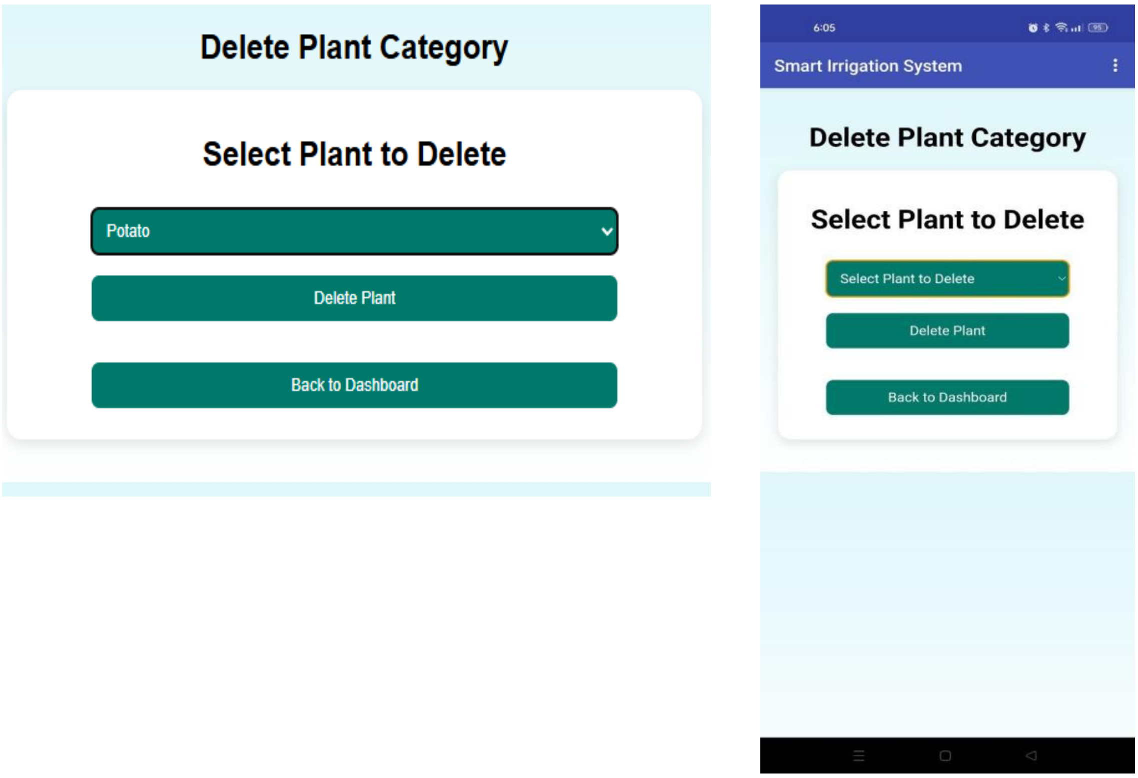

Figure 4.5: Delete Plant Category

Switch to Automated and Manual.

This section uses for make the system automated and manual depending on the user choice. User can set the mode from this function.

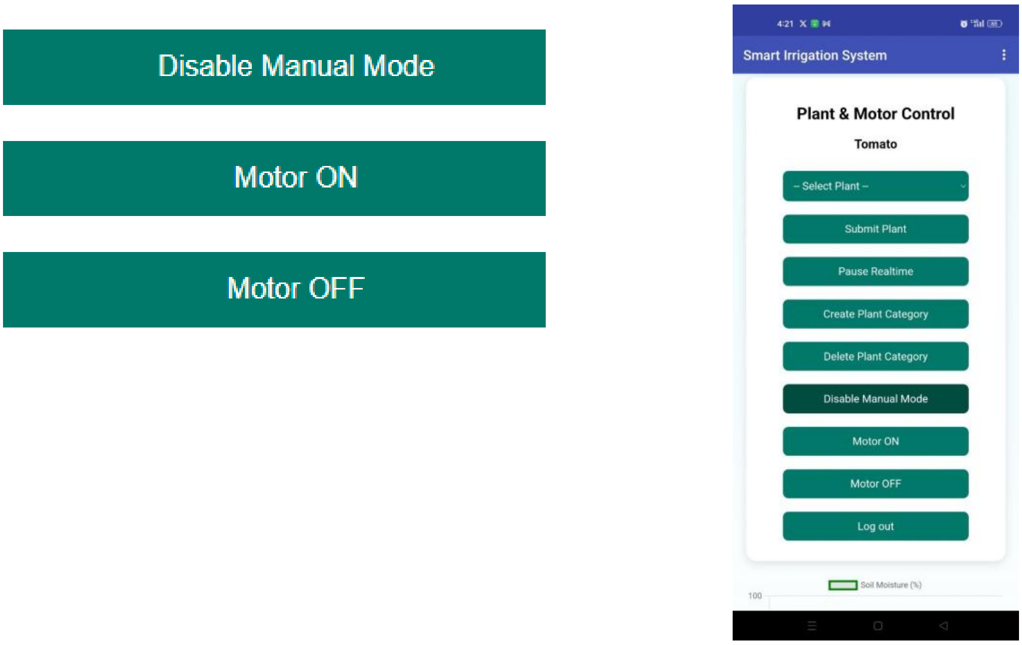

Figure 4.6: Automatic and Manual Mode

Logout

When the plant setup complete user can logout the account and the page go to the login page. So that is the process of web and mobile application UI design that easy to control the irrigation system.

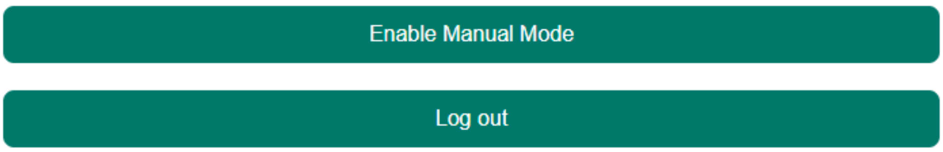

Figure 4.7: Logout Dashboard

4.4 Summary

This chapter represents a complete overview of the environment setup like evaluation, testing, performance, and impact of the Smart Irrigation System project. We defined how the hardware and software work well in environments and prepared by using ESP32, sensors, Firebase integration, and the web and mobile applications. The results and discussion presented in this chapter validate the functional efficiency, accuracy, and practicality of the proposed IoT-based Smart Irrigation System. A series of tests were conducted under both laboratory and real-field conditions to ensure that each module—from sensor calibration to data transmission—worked reliably. The ESP32 microcontroller successfully handled sensor data collection and real-time decisions for motor control. Soil moisture sensors accurately detected changes in moisture levels and triggered the motor pump accordingly. The temperature and humidity sensors provided stable readings, while the rain sensor was instrumental in automatically halting irrigation during rainfall, thus reducing water waste. The PIR motion sensor also contributed to system security by detecting movements in the vicinity. Motor control was precise and responsive, managed through the L298N motor driver based on sensor inputs. The OLED display updated real-time values locally, providing a quick reference for users on-site. In addition, the integration with Firebase Realtime Database ensured seamless cloud synchronization, which enabled real-time monitoring and control via the web and mobile applications. These apps offered users a secure and intuitive interface through Firebase Authentication, enhancing system accessibility.

The power system, based on a 12V battery recharged by a 30W solar panel, proved highly sustainable. It maintained uninterrupted operation throughout testing phases, validating the system's energy efficiency and off-grid capability. Overall, this chapter demonstrates that the system is reliable, scalable, and ready for deployment in real agricultural environments where automation and sustainability are crucial.

Chapter 5

Engineering Standards and Design Challenges

This chapter presents the observed results, discusses the system's performance, and evaluates it against the expected outcomes. It also includes screenshots and logged data analysis.

5.1 Compliance with the Standards

In the development of the smart irrigation system there have several standards were considered to ensure compatibility and safety and reliability. The key standards relevant for the project are given.

5.1.1 Software Standards

IEEE 830-1998 (Software Requirements and Specification)

- Description: To define the recommended practices to write the software requirements specifications.
- Application: To help to make documenting clear with requirements for sensors data acquisition and motor control logic with Firebase integration and user interface features.

IEEE 1016-2009 (Software Design Descriptions)

- Description: It Provides standard practices to make a standard documenting using software design.
- Application: It applied when architecture design of ESP32 firmware and database structure in Firebase also the web and mobile applications.

ISO/IEC 25010:2011 (Software Product Quality)

- Description: To define the quality attributes such as reliability and usability and performance also maintainability.
- Application: To make sure the web and mobile applications meet user-friendly standards and the system is capable in sensor data handling and motor control system.

Web Standards (HTML5, CSS3, JavaScript)

- Description: To make industry standards for web development.
- Application: To make a user-friendly and responsive web application to monitor real-time sensor data.

5.1.2 Hardware Standards

IEEE 802.11 (Wi-Fi Standards)

- Description: To define wireless communication protocol using ESP32 microcontroller.
- Application: To ensure a stable Wi-Fi communication between the ESP32 and the Firebase database.

IEEE 1451 (Smart Transducer Interface Standard)

- Description: It gives a standard interface to make a connection with smart sensors and actuators to networks.
- Application: Considered when integrating soil moisture sensors such as DHT11, temperature and humidity sensor and PIR motion detect sensors.

5.1.3 Communication Standards

Communication standards define the protocols and methods that enable reliable data exchange between devices, systems, or networks in a project. These standards ensure compatibility, interoperability, and consistent performance across all components involved. In this project, several communication standards are utilized:

UART (Universal Asynchronous Receiver-Transmitter)

Used for serial communication between microcontrollers and modules and SD card module. UART enables simple, reliable point-to-point data transmission.

I²C (Inter-Integrated Circuit)

A multi-master, multi-slave serial bus standard used for communication between the ESP32 and peripheral sensors such as the DHT11 temperature and humidity sensor. I²C reduces wiring complexity by using only two lines.

SPI (Serial Peripheral Interface)

Employed for high-speed data transfer between the ESP32 and the SD card module. SPI's full-duplex communication and faster clock speeds make it ideal for logging sensor data to a CSV file.

Wi-Fi (IEEE 802.11 b/g/n)

The ESP32's built-in Wi-Fi module is used to connect the system to a wireless network, enabling real-time synchronization of sensor data with Firebase Realtime Database.

HTTP / REST API

Communication between the ESP32 and Firebase backend typically relies on HTTP requests following the REST architecture, allowing secure and structured data exchange.

5.2 Impact on Society, Environment and Sustainability

The smart irrigation system is deployed to get a positive impact on society. It makes the environment and long-term sustainability goals while it applied.

Impact on Society:

The smart irrigation system is a good approach for society. Now a days growing crops are very challenging for farmers. By irrigation manually is very long-term process and costly for the farmers. Also, water is the main source to grow the crops. To reduce the water wastage, it gives the good impact in society and save farmer cost. This irrigation system may apply in long area or the small areas and it suits in every environment. So, it's a beneficial approach for the society.

Impact on Environment:

Most of the agriculture area there use shallow pump that works with desal oil. This oil makes water pollution and gives the bad impact in water and fish farming. Beside it pollutes soil and that's why crops root may damage also it pollute the air that is wildly impact in the environment. to use smart irrigation system, it reduces the pollution and makes the environment healthy and purified. By using the solar panel, it does not need to supply the power from external power source and reduce the farmer cost to irrigate the agricultural areas.

Impact on Sustainability:

The project commits to lot of UN Sustainable Development Goals (SDGs), including produce clean water and sanitation (SDG 6), liable utilization and production (SDG 12) and climate action (SDG 13). By developmental efficient use of water and energy resources by the system supports sustainable agricultural areas. It helps to reduce the environmental footprint of farming action.

5.2.1 Impact on Life

Ther has several impacts in life. Smart irrigation system IoT based is the solution key for the farmers. Because farmer do the irrigation manually that makes costly and need to hire the labor for the irrigation in agricultural areas. Now our proposal is to make it user friendly and make positive impact in life.by using this project farmer don't need to hire the labor and don't wait for the irrigation process this helps to work fast and perfect so that farmer can work more and crops grow well.

5.2.2 Impact on Society & Environment

The implementation IoT-based smart irrigation system brings substantial positive impacts on both society and the environment.

From a societal perspective the smart irrigation system contributes to improving agricultural action using automated irrigation system and real time data display for enabling farmers to adopt more data-driven. It empowers small-scale farmers with the help of reduce dependency on guesswork and manual monitoring in the field also bridging the technological gap to the farmer between traditional and modern agriculture. Also, the real time monitoring feature and remote control through web and mobile applications are make good impact in society and environment.

5.2.3 Ethical Aspects

The IoT-based smart irrigation system development and deployment is involving several ethical considerations that were carefully addressed during the project deploy mentation.

First, data privacy and security, there we provide the firebase authentication that helps to login the user using the valid email and password. Since the system collects real-time data such as soil moisture, temperature, humidity and stores it in Firebase that was essential to ensure that user authentication is properly implemented to the protect against unauthorized access for security purpose. By using Firebase Authentication, it helps to ensure that only authorized users can access and control the system otherwise no one can get the access to control the device.

5.2.4 Sustainability Plan

The sustainability of the IoT-based smart irrigation system is to its design and implementation that more efficient to use. This project system is built with long term process due to lack of knowledge. After all the system is properly done for the irrigation process and task.

In our IoT based smart irrigation system, we deployed a 30w solar panel that charge the system battery easily and handle all the askes. To make it energy saving and produce the free energy it is the big solution for the problem in agricultural areas. Because it cost efficient and farmer can able to affordable for this irrigation system project. The solar panel's capacity has been selected to ensure continuous operation, even in low-light conditions, ensuring long-term sustainability.

5.3 Project Management and Financial Analysis

For the clear understanding of our project costs and potential revenue streams that is essential for assessing the viability and scalability for smart irrigation system. We discuss with detailed cost analysis featuring two budget scenarios Basic and Enhanced along with the rationale for each followed by the proposed revenue model.

Table 5.1: This is Project Budget Table

Se. No.	Equipment	Model	Quantity	Cost
1	ESP32	ESP32-S2	2	4,400
2	Soil moisture sensor	Capacitive sensor	4	2000
3	12 Volt Relay	12vRelay module	2	300
4	Water Pump 12v	AD20p-1230A	1	850
5	LCD Display	16x2 serial LCD monitor	1	440
6	Wi-Fi module	DT-06 TTL to WIFI Module	1	550
7	Humidity sensor	DHT22 AM2302 sensor	1	726
8	Temperature Sensor	TM36	2	400
9	Bread Board	MB102 Large	2	350
10	Jumper wire	Male to Male, Male to Female,	3	600
11	Adapter 12v	12v 2A adapter	1	1500
12	12 v battery	12V5A_battery	1	2000
13	Water pipe	PVC pipe flexible 6 feet	1	1500
14	PVC Project Board	PVC FOAM 6mm	10	1700
15	Water tank	15L water tank RFL	1	2000
16	Display module I2c	i2c module	2	300
17	Circuit board	Veroboard	5	200
18	Shoulder Iron Kit	Shoulder Iron Kit	1	5000
19	Hand drill kit	Hand drill	1	4000
20	Mono Solar Panel+ Controller	30w mono+ controller	1	3,000
21	PIR Sensor	Pir motion Sensor	8	1,800
22	Soil tray	2.5feet by 2 feet	1	2000
23	Motor Driver	L298N	2	840
			Total	36,456

5.4 Complex Engineering Problem

5.4.1 Complex Problem Solving

Power Management

Since the system needs to run all the time, we implement the power management often on batteries or solar power, we carefully had to manage energy use by using hardware sleep modes and writing energy-efficient software.

Environmental Durability

Our system works on outdoors that's why we had to protect it from rain, dust, and temperature changes we make the project in a waterproof box. This meant choosing weather-resistant all the components and strong enclosures.

Sensor Accuracy and Calibration

we chose the best senor and best controller that able to read accurate data from Agri land. The soil moisture sensor read the moisture accurately so that motor response accurately. otherwise, the system may damage or fail to work.

Scalability and Communication

The system should work not just for one field but also many fields with the help of multiple sensors. We ensure the communication technologies like Wi-Fi, LoRa, or GSM could handle this without losing any data.

Data Security and Privacy

Since the system connects to the cloud for example, Firebase. We need to ensure to make sure data is transmitted securely using encryption and proper authentication that we get from firebase.

User-Friendly Interface

We designed the web and mobile application to make easy to control the system properly. We made user friendly interface and best optimization too easy to understand.

Table 5.2: Mapping with complex problem solving.

EP1 Dept of Knowledge	EP2 Range Of Conflicting Requirements	EP3 Depth of Analysis	EP4 Familiarity of Issues	EP5 Extent of Applicable Codes	EP6 Extent Of Stake-holder Involvement	EP7 Interdependence
✓		✓		✓	✓	✓

EP1- Depth of Knowledge:

This project involves in integration of several sensors and modules such as soil moisture, DHT11, PIR, SD card module that requiring a solid understanding of embedded systems. The sensor interfacing and show real time data processing. The depth of knowledge represents an advance level of understanding necessary for the complex problem solving.

EP3- Depth of Analysis:

The system that was designed after analyzing multiple environmental conditions like temperature, humidity, soil moisture and human presence. The system collects the data from sensors that was deeply analyzed to determine threshold values and to trigger automated actions based on condition, such as irrigation or alert mechanisms.

EP5 - Extent of Applicable Codes:

The project was complied with various coding and standards suitable for embedded systems also IoT communication protocol. Make structured programming, error handling and Firebase integration to ensure the system is reliable and maintainable for this project.

EP6 - Extent of Stakeholder Involvement:

The solution considered with different stakeholders like farmers and agricultural technicians and environmental engineers. Their needs influenced features like real-time monitoring, moisture-based irrigation control and data logging into SD card for future analysis.

EP7 - Interdependence:

The project components are highly interdependent with the system, soil moisture data influences motor operation while PIR detection activates it shows object found. This sensor of components reflects a complex system with multiple dependent variables working together in system.

Mapping with Knowledge Profile for EP1

Table 5.3: Mapping with knowledge Profile.

K3 Engineering Fundamentals	K4 Specialist Knowledge	K5 Engineering Design	K6 Engineering Practice	K8 Research Literature
✓	✓	✓	✓	✓

K3 - Engineering Fundamentals:

The project is a part of grounded in engineering fundamentals and particularly electronics like microcontrollers and sensor operation. The concepts of this project such as voltage regulation, signal processing, and timing that critical in circuit design and programming.

K4 - Specialist Knowledge:

For this project it is mandatory to specialist knowledge in IoT systems and embedded programming that was essential to implement Firebase database for integration system and SD card data logging.

K5 - Engineering Design:

To make the project simple and perfect a structured engineering design process was followed from requirement analysis and component selection with circuit designing and coding also testing for the integration system. The design also includes mechanisms with safety and fault tolerance.

K6 - Engineering Practice:

The practical implementation of hardware and software was the key to this project. Troubleshooting sensor malfunctions and debugging code and managing power distribution were the part of daily tasks that demonstrating real-world engineering practice.

K8 - Research Literature:

The project referenced various datasheets like IoT application notes and academic literature on smart agriculture and embedded systems. This background research guided us to the selection of sensors microcontroller modules and communication protocols.

5.4.2 Engineering Activities

In our IoT Smart Irrigation System there have several engineering activities, were carefully planned and deploy to achieve efficient and user-friendly solution for the farmer.

We make the applications web and mobile based that make the system control properly and get the useful for any users. In mobile app there use control and motor management also plant categories for the plant selection and modify the irrigation system based on use requirement.

The next step was hardware integration where we combined several components including the ESP32, soil moisture sensors, temperature sensor and humidity sensor and PIR sensor. The motor driver produces the power for the motor and make it fundamental electronics knowledge that essential to match voltages and handle pin connections also and troubleshoot issues.

For the software we use Arduino IDE to upload the code that operate the system. We aimed on writing efficient, modular code for handling the sensor data collection and device control also real-time communication with the Firebase cloud platform.

Table 5.4: Mapping with complex engineering activities.

EA1 Range of re-sources	EA2 Level of Interaction	EA3 Innovation	EA4 Consequences for society and environment	EA5 Familiarity
✓	✓	✓	✓	

EA1 - Range of Resources:

The project using a wide range of engineering resources like hardware components and software tools and communication protocols. The integration of diverse resources for this project reflects the project's complexity and engineering depth.

EA2 -Level of Interaction:

This system displays significant interaction between components of hardware and software control logic. The sensors collect data from environment that is processed by the ESP32S which in turn interacts with Firebase communication protocol like triggers actuators and sends object detection alerts. The undisturbedly integration between multiple subsystems demonstrates with a high level of system interaction.

EA3 - Innovation:

The project offers an innovative approach to make a smart agriculture by combining automated irrigation with motion-based security also cloud synchronization and real-time logging. This project multifunctional capability tailored for the remote agricultural settings to enhances productivity and resource management.

EA4 - Consequences for Society and Environment:

This smart irrigation system contributes for saving water wastage and sustainable agriculture directly addressing environmental concerns. By optimizing irrigation based on real-time soil data, the project can help to reduce water wastage and improve crop yield healthy, positively impacting farmers and the broader community

5.5 Summary

This project shows the application of complex engineering concept using the integration of various sensors and actuators and the communication modules for developing a smart irrigation system. The system requires in-depth knowledge of embedded systems and data analysis and IoT-based cloud interaction that fulfilling multiple criteria under complex problem solving (EP1, EP3, EP5, EP6, EP7). From a knowledge viewpoint, the project incorporates main engineering fundamentals (K3), specialist and design knowledge (K4, K5) hands-on implementation (K6) and research insights (K8) through back a strong knowledge profile required for addressing real-world challenges. With regard to engineering activities, the project represents a broad range of resources (EA1) that high interaction between system components (EA2) and an innovative all-purpose solution (EA3). It also think about societal and environmental impacts (EA4) by developing sustainable water use and enhanced agricultural productivity.

Chapter 6

Conclusion

This chapter summarizes the findings and effectiveness of the project. It also discusses potential future enhancements and broader applications of the system.

6.1 Summary

This chapter conferred an overview of the engineering standards and societal and environmental impacts in real life. Also, this project focused on management and financial analysis and design protest in our IoT Smart Irrigation System project. It represents how to the project works in problem-solving requirements and maps to the knowledge profile also. Finally, this proposed project focused to the deliver for a sustainable efficient and user-friendly solution to make modern agriculture that is helpful to all farmers.

This project developed successfully an IoT-based smart irrigation system that aimed to improve water uses efficiency so that the water my not waste anymore and automating agricultural irrigation.in this project by integrating sensors such as soil moisture, rain, and temperature sensors and an ESP32 controller that connect to Firebase to see the real-time database, and a web application and make it user friendly.

6.2 Limitation

While the system achieved its core program and get several limitations were borne. The system's performance able to be affected by unstable internet connectivity. Especially in remote agricultural areas and second, the power management of battery life and need further improvement to ensure continuous operation. especially when conditional on solar energy. In this project the system currently uses predefined threshold values of soil moisture which may not suit well to different crop types or changing environmental conditions without manual adjustments.

6.3 Future Work

In future work we will add GSM module that helps to operate the system without the Wi-Fi system so that all the time the devices connected with the cloud storage.

Also add the manual irrigation physically that also operate when user close to the system devices. We focused to build the own customized backend database connection so that the limitation may not affect in the work place to develop the irrigation system project. We will make it more effective and enhance to all user.
We will deploy a custom server by the help of Raspberry pi and opensource operating system. We will use AI and machine learning to predict the irrigation timely and also add weather Forecast to make the irrigation system more efficient.

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