MAJOR PROJECT
SMART IRRIGATION SYSTEM USING IOT

Submitted for the partial fulfillment of the requirement for the award of a Degree

B.TECH IN

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

UNIVERSITY INSTITUTE OF TECHNOLOGY, RGPV, BHOPAL

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DECLARATION BY THE CANDIDATES

We hereby declare that the work which is being presented in the Report of Major Project entitled **"SMART IRRIGATION SYSTEM USING IoT"** our own work, submitted for the partial fulfillment of the requirement for the award of a bachelor's degree in Computer Science & Engineering. The work which has been carried out at the University Institute of Technology, RGPV, Bhopal in the of session 2023-2024, and an authentication record of our work carried out under the guidance of the **Dr. Anjna J Deen** Department of Computer Science & Engineering **Prof. Manish Mishra** Department of Computer Science & Engineering, University Institute of Technology, RGPV Bhopal.

I further declare that, to the best knowledge, the matter written in this project has not been submitted for the award of any other Degree.

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CERTIFICATE

This is to certify that **Tapish Patidar, Vaibhav Patidar, Praveen Ahirwar and Ritesh Warwade** of B.Tech 4thYear, Computer Science & Engineering have completed their Major Project entitled **"SMART IRRIGATION SYSTEM USING IoT"** during the academic year 2023-2024 under my guidance and supervision.

We approve the project for the submission for the partial fulfillment of the requirement for the award of a degree in Computer Science & Engineering.

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ABSTRACT

We know that our indian economy is the largest economy in the world. Agriculture sector, its biggest contribution is economy sevice, which develops manpower. The engineer is making his contribution by using different types of technology in the agriculture sector.

If we talk about indian farmers, all are affected due to famine, which dries up the crops and they are not able to focus on the crops, so in view of these problems, automatic irrigationplant system should be installed in the agricultural area so that the crops are watered time totime.There should be supply of water so that our crops can be saved from damaged.

The concept of a Smart Irrigation System utilizing the Internet of Things (IoT) has emergedas a promising solution for addressing water scarcity and optimizing agricultural practices. This abstract presents an overview of a smart irrigation system that incorporates IoT technologies to improve water management efficiency and enhance crop yields.

The proposed system integrates various components, including sensors, actuators, a central control unit, and cloud-based services. Soil moisture sensors are deployed in the field to continuously monitor the moisture levels in the soil. Weather sensors provide real-time dataon temperature, humidity, and rainfall. These sensor readings are transmitted wirelessly tothe central control unit, which acts as the brain of the system.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Irrigation is a scientific process of artificially supplying water to the land or soil that is being cultivated. Traditionally in dry regions having no or little rainfall water had to be supplied to the fields either through canals or hand pumps, tube wells. Conventional irrigation methods had severe problems such as increase in workload off arm labor and often it lead to problem such as over-irrigation or under-irrigation and leaching of soil .

To develop android based automatic Farming system capable of controlling many electrical appliances in an irrigation or field using android platform with a mobile handset, where data transmission is carried wirelessly. That's why designs Wireless transmission media using Wi- Fi transceivers and its interfacing peripherals for wirelessdata communication between Mobile Handset and appliances is our need. Hence tocreate a database of user interface in order to characterize the electric signals to atomizefarming system. And to develop the GUI interface to monitor and change the current statusof field on any android smart phones. Another important point is not only monitor the temperature and maintain moisture level in the field for proper growth of plants but also save water, Energy and manpower in the agriculture Sector. So we design such a systemthat will be efficient and effort reducing of the farmer. Hence we design the System which is operated manually as well as automatically from remote locations by using Node MCU.

The expected outcomes encompass significant water conservation, improved crop yield, a user-friendly interface for remote monitoring, and the incorporation of energy-efficient components. The significance of this project lies in its potential to empower farmers, promote resource efficiency, and address global challenges related to water scarcity in agriculture. In conclusion, the Smart Irrigation System using IoT project is poised to makea substantial impact on modern agriculture by ushering in more sustainable farmingpractices and contributing to the long-term viability of agricultural activities.

The "Smart Irrigation System Using IoT" project aims to revolutionize agricultural water management by integrating Internet of Things (IoT) technology into irrigation practices. Traditional irrigation methods often result in significant water wastage and inconsistent crop growth due to the lack of precision and real-time data. This project addresses these challenges by deploying soil moisture sensors, temperature sensors, and humidity sensors across agricultural fields to collect real-time data. The data is processed by a microcontroller, such as an Node MCU, which uses predefined algorithms to determine the optimal irrigation schedule. The system utilizes wireless communication modules like Wi-Fi to transmit data to a central server for remote monitoring and control.

1.2 Objective :

The primary objective of the major project on the "Smart Irrigation System using IoT"is to address the inherent inefficiencies in conventional agricultural irrigation practices through the development and implementation of an advanced and intelligent irrigation system. At the core of this initiative is the integration of Internet of Things (IoT) technologies to create a responsive and data-driven irrigation solution. The project aims to mitigate challenges associated with water wastage and suboptimal crop yield by deploying a network of soil moisture sensors and weather sensors throughout the agricultural field. These sensors will facilitate real-time data collection, offering insightsinto soil conditions and weather patterns.

The specific technical objective is the development of an intelligent irrigation control system that leverages the data gathered by the sensors. Automated valves and pumpswill be incorporated to enable precise and timely adjustments to the irrigation schedule based on the actual needs of the crops. This adaptive approach to irrigation aims to maximize water efficiency, ensuring that crops receive the appropriate amount of moisture for optimal growth without unnecessary overwatering. Additionally, the system will be designed to operate autonomously, reducing the manual effort required byfarmers and enabling a more streamlined and efficient irrigation process.

Furthermore, the project aims to provide farmers with remote monitoring and control capabilities through a user-friendly interface accessible via web or mobile applications. This objective seeks to empower farmers by allowing them to remotely observe thestatus of the irrigation system, monitor soil conditions, and make informed decisions about irrigation schedules. By enhancing accessibility and usability, the project aims to ensure that the benefits of the Smart Irrigation System are practical, user-centric, and aligned with the needs of agricultural stakeholders.

In summary, the major project seeks to achieve a multifaceted objective: the development and implementation of a Smart Irrigation System using IoT that optimize water usage, enhances crop yield, and empowers farmers with advanced monitoring and control capabilities. Through the successful realisation of these objectives, the project aims to contribute to the advancement of precision agriculture, fostering sustainable and efficient practices in the realm of irrigation.

The primary objective of the "Smart Irrigation System Using IoT" project is to enhance the efficiency and effectiveness of agricultural water use through the implementation of advanced IoT technologies. This system aims to reduce water wastage by utilizing precise, real-time data from soil moisture, temperature, and humidity sensors to optimize irrigation schedules. By automating the irrigation process, the project seeks to minimize human intervention, thereby reducing labor costs and the potential for human error. Additionally, the project aspires to improve crop yields by ensuring that plants receive the optimal amount of water at the appropriate times, based on current environmental conditions. Ultimately, the project endeavors to promote sustainable agriculture practices, contributing to better resource management and environmental conservation.

1.3 What is IoT :

The Internet of Things (IoT) represents a transformative technological landscape wherethe physical world converges with the digital through a network of interconnected devices. In essence, IoT involves embedding everyday objects with sensors, software, and connectivity, enabling them to collect and exchange data. These "smart" devicescan communicate with each other and with centralised systems, creating an ecosystem where information flows seamlessly between the physical and virtual realms. The sheer diversity of IoT applications is staggering, ranging from smart homes and cities to industrial processes, healthcare, and agriculture. In smart homes, for instance, IoTdevices like thermostats, cameras, and appliances can be remotely controlled and monitored, enhancing convenience and energy efficiency. In industrial settings, IoT facilitates predictive maintenance, real-time monitoring, and optimisation of processes, leading to improved productivity and cost savings. The healthcare sector benefits from IoT-enabled devices that track patient data, enabling timely interventions and personalised treatments. However, the proliferation of IoT also raises concerns about privacy, security, and the ethical implications of massive data collection. As IoT continues to evolve, the potential for innovation is immense, promising to reshape how we interact with our surroundings and how businesses and industries operate, ultimatelyushering in a new era of connectivity, efficiency, and intelligence.

1.4 Applications and needs of IoT:

There are several ways individuals and businesses can help leverage IoT in real life to maximise its benefits. Here are some suggestions:

Stay Informed: Keep up-to-date with the latest developments and trends in IoT technology. Stay informed about new devices, applications, and use cases across different industries. This knowledge will help you identify opportunities to implement IoT solutions in your personal or professional life.

Embrace Smart Home Devices: Start incorporating IoT-enabled devices into your home, such as smart thermostats, lighting systems, security cameras, and appliances. These devicescan enhance convenience, energy efficiency, and security while providinga firsthand experience of how IoT technology can improve daily life.

Explore Industry-Specific IoT Solutions: Research industry-specific IoT solutions and identify how they can address challenges or improve operations in your field. Whether it's agriculture, healthcare, manufacturing, or logistics, there are numerous IoT applications that can enhance efficiency, reduce costs, and drive innovation.

Seek Collaboration and Partnerships: Collaborate with IoT solution providers, technology experts, and industry peers to explore and implement IoT projects. By partnering with experts in the field, you can gain insights, access resources, and develop customize d IoT solutions that cater to your specific needs and objectives.

Promote Data Security and Privacy: IoT devices collect and transmit vast amounts of data, often of a sensitive nature. It is crucial to prioritize e data security and privacy. Ensurethat IoT devices and systems are protected against cybersecurity threats by implementing robust security measures, such as strong passwords, encryption, andregular software updates.

Educate and Up skill: Take advantage of training programs, workshops, and online courses to enhance your understanding of IoT concepts, technologies, and implementation strategies. Up skilling yourself and your team will enable you to make informed decisions and effectively utilise IoT in real-life scenarios.

Advocate for IoT Adoption: Spread awareness about the benefits of IoT and advocate for its adoption in your community, workplace, or industry. Highlight real-world successs storiesand the potential for cost savings, increased efficiency, and improved quality of life.Encourage stakeholders to explore and invest in IoT solutions that can address specific challenges and drive innovation.

Support Standards and Interoperability: Promote the adoption of IoT standards and interoperability frameworks that enable seamless integration and communication between different IoT devices and systems. Standardization plays a crucial role in ensuring compatibility, scalability, and future-proofing of IoT solutions.

Contribute to Open-Source IoT Projects: If you have technical expertise, consider contributing to open-source IoT projects. Open-source initiatives foster collaboration, innovation, and knowledge-sharing, benefiting the broader IoT community.

Cost Reduction: Efficient use of water and energy resources can lead to significant cost savings for farmers. IoT systems help in reducing operational costs by minimizing water and fertilizer usage and lowering energy consumption.

Real-time Decision Making: Farmers need timely and accurate information to make informed decisions. IoT provides real-time data on various environmental factors, enabling quicker and more effective decision-making processes.

Increased Crop Yields: Farmers need to maximize crop yields to meet the growing food demand. IoT technology provides precise and timely irrigation, which helps maintain optimal soil moisture levels, leading to healthier crops and higher yields.

1.5 Tools & Technology used in IoT:

The key components of an IoT system include:

Devices and Sensors: These are the physical objects or devices embedded with sensors,actuators, and connectivity modules that enable them to collect and transmit data.

Connectivity: IoT devices use various communication protocols, such as Wi-Fi, Bluetooth,or cellular networks, to connect to the internet and transmit data.

Data Processing: The data collected by IoT devices is processed and analyzed either locally on the device or in the cloud. This processing helps derive meaningful insights and enables intelligent decision-making.

Cloud Services: Cloud platforms provide the infrastructure for storing, processing, and analyzing the vast amount of data generated by IoT devices. Cloud services also facilitate remote access and control of IoT devices.

Applications and User Interfaces: IoT applications and user interfaces allow users to

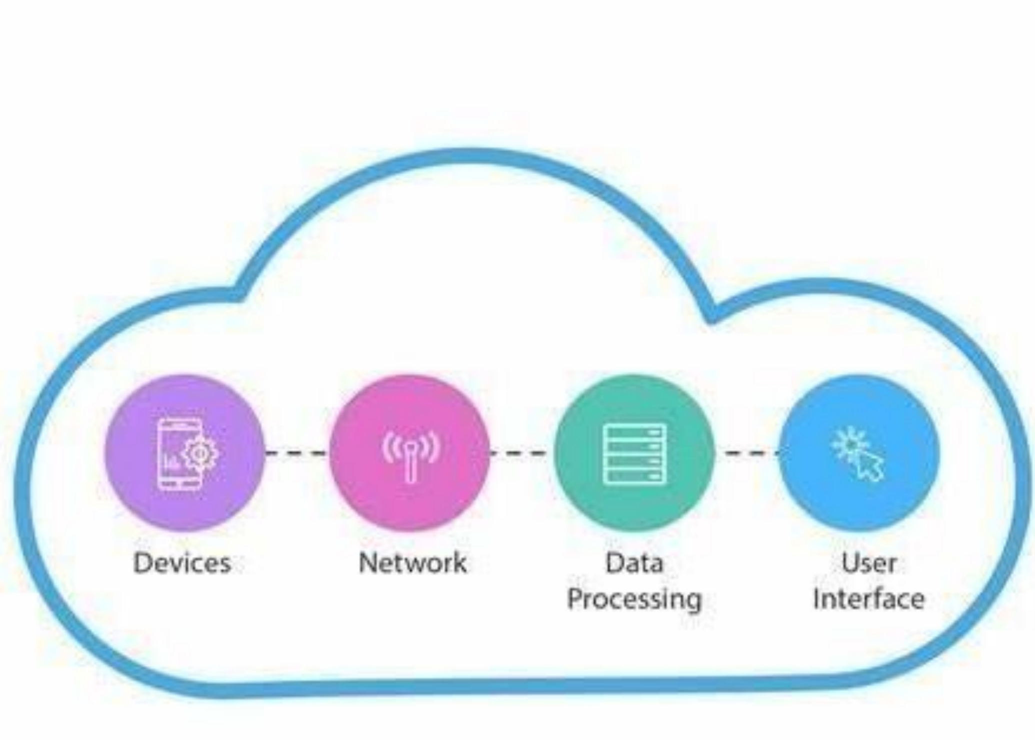

Fig:1 Tools of IoT

1.6 Technologies Used :

IoT (Internet of Things) relies on a variety of technologies to enable the connectivity, data exchange, and intelligent functionality of interconnected devices. Here are some key technologies commonly used in IoT:

Wireless Connectivity: IoT devices communicate with each other and with the internetusing wireless communication protocols. Popular wireless technologies include Wi-Fi, Bluetooth, Zigbee, Z-Wave, NFC (Near Field Communication), RFID (Radio Frequency Identification), and cellular networks (2G, 3G, 4G, and emerging 5G).

Sensors and Actuators: Sensors are used to capture data from the physical environment, such as temperature, humidity, light, pressure, motion, and more. Actuators,on the other hand,enable devices to perform physical actions based on received data, suchas turning on/off lights,opening/closing doors, or controlling motors.

Embedded Systems: IoT devices often consist of embedded systems, which are specialised computer systems designed for specific functions. These systems typically include microcontrollers or microprocessors, memory, and software/firmware to controldevice operations and data processing.

Cloud Computing: Cloud platforms play a significant role in IoT by providing storage,processing power, and analytics capabilities. IoT devices can transmit data to the cloud for storage, analysis, and access from anywhere. Cloud platforms offer scalable infrastructure, data processing services, and APIs for seamless integration with other applications.

Edge Computing: Edge computing involves processing data near the IoT devices themselves, instead of sending all data to the cloud. This approach reduces latency, conserves bandwidth, and enables real-time decision-making. Edge devices or gateways have computational capabilities to process data locally, perform analytics, and execute actions.

Data Analytics and Artificial Intelligence (AI): IoT generates vast amounts of data, and analytics and AI technologies are used to derive insights and make intelligent decisions. Machine learning algorithms can analyze patterns, predict behavior, and optimize operations based on the collected data, enabling predictive maintenance, anomaly detection, and personalized services.

Security and Privacy: IoT security is crucial to protect against unauthorized access, data breaches, and privacy violations. Security measures include encryption, authentication mechanisms, secure communication protocols, and device management practices. Privacy considerations involve data anonymization, user consent.

1.7 Future Scope :

The future scope for the major project on the "Smart Irrigation System using IoT" is highly promising, with numerous opportunities for expansion, refinement, and broader impact. As technology continues to advance, the integration of artificial intelligence(AI) and machine learning (ML) into smart irrigation systems holds great potential. These advancements could enable the system to learn and adapt to changing environmental conditions, further optimizing irrigation schedules based on historical data and predictive analytics. Additionally, the incorporation of satellite imagery and remote sensing technologies could provide a comprehensive view of larger agricultural landscapes, allowing for a more holistic and precise approach to irrigation management.Furthermore, the scalability of the project is a key aspect of its future scope. Initially designed for smaller agricultural plots, the smart irrigation system could be adapted for use in larger commercial farms. Collaborations with agricultural research institutions and partnerships with governmental agricultural agencies could facilitate the implementation of the system on a broader scale, contributing to sustainable water management practices at the regional or even national level.

In the context of global challenges such as climate change and water scarcity, the smart irrigation system could play a crucial role in resilience-building for farmers. Future iterations of the project may explore the integration of weather prediction models, allowing the system to proactively adjust irrigation schedules in anticipation of extreme weather events. This proactive approach can help mitigate the impact of adverse weather conditions on crops, enhancing overall agricultural productivity.

Moreover, the project could extend its focus beyond traditional crop irrigation to encompass emerging fields such as vertical farming and greenhouse cultivation. These innovative agricultural practices, often characterized by controlled environments, could benefit significantly from the precision and adaptability offered by a smart irrigation system, leading to more efficient resource utilization and higher yields.

In conclusion, the future scope for the smart irrigation system using IoT is expansive.By embracing emerging technologies, scaling its implementation, and diversifying its applications, the project has the potential to contribute significantly to the evolving landscape of precision agriculture, playing a vital role in sustainable and resilientfarming practices on a global scale.

1.8 Limitations:

The major project on the "Smart Irrigation System using IoT" faces several limitations that warrant careful consideration during its implementation. Firstly, power constraints may posea challenge, especially in remote agricultural areas where a consistent and reliable power supply may be lacking. The deployment of sensor nodes, communication devices, and other IoT components requires a sustainable energy source. Exploring alternative energy solutions, such as solar power, becomes essential to ensure the autonomy and effectiveness of the system. Another limitation pertains to the accuracy of sensor data. Soil moisture sensors, for instance, may exhibit variations in readings due to factors like soil composition and sensor calibration. Calibrating and maintaining sensors regularly is crucial to ensure the accuracy of data, as imprecise information could lead to suboptimal irrigation decisions, defeating the purpose of the smart irrigation system.

Furthermore, the interoperability of different IoT devices and platforms poses a potential limitation. In the absence of standardized protocols, integrating diverse components into a cohesive system may be challenging. Compatibility issues between sensors, communication technologies, and the central control system need to be carefully addressed to create a seamless and efficient smart irrigation infrastructure.

Data privacy and security concerns are paramount limitations. The collection of sensitive agricultural data necessitates robust security measures to protect against unauthorized accessand data breaches. Implementing encryption protocols, secure data storage practices, and compliance with relevant data protection regulations become imperative to instillconfidence in users and safeguard the integrity of the system.

Lastly, the socio-economic context and user acceptance are critical considerations. The success of the smart irrigation system hinges on the willingness and ability of farmers to adopt and adapt to the technology. Factors such as education, awareness, and the cultural context of farming communities play a crucial role in determining the feasibility and acceptance of the system.

CHAPTER 2

LITERATURE SURVEY / RELATED WORK

2.1 Survey Report

In Irrigation Control System Using Android and GSM for Efficient Use of Water and Power – Tam, S., Nyvall, T. J. and Brown, L. (2005). C [3] Automated irrigation system uses valves to turn motor ON and OFF. These valves may be easily automated by using controllers. Automating farm or nursery irrigation allows farmers to apply the right amount of water at the right time, regardless of the availability of labor to turn valves on and off. In addition, farmers using automation equipment are able to reduce runoff from over watering saturated soils, avoid irrigating at the wrong time of day, which will improve crop performance by ensuring adequate water and nutrients when needed. Those valves may be easily automated by using controllers.

Automating farm or nursery irrigation allows farmers to apply the right amount of water at the right time, regardless of the availability of labor to turn valves on and off. They lack in a featured mobile application developed for users with appropriate user interface. It only allows the user to monitor and maintain the moisture level remotely irrespective of time. From the point of view of working at remote place the developed microcontroller based irrigation system can work constantly for indefinite time period, even in certain abnormal circumstances. If the plants get water at the proper time then it helps to increase the production from 25 to 30 % [5] Remote Sensing and Control of anIrrigation System Using a Distributed Wireless Sensor Network Jha, K., Doshi, A., Patel, P. and Shah, M. (2019) [6] The setup of technical system describe in this paper is broad based and is relatively one of the efficient system that has developed windows application to monitor the field. Field is equipped with wireless communication sensors that avails better facilitated sensor communication and covers wider field area. Detailed description on site field sensors and Internet technology is described briefly.

The statistical data provided is measured to be efficient and used for research work. Microcontroller Based Automatic Plant Irrigation System R. Kumar and D. R. Patel [7] The main aim of this paper is to provide automatic irrigation to the plants whichhelps in saving money and water.

The entire system is controlled using 8051 micro controller which is programmed as giving the interrupt signal to the sprinkler. A wireless application of drip irrigation automation supported by soil moisture sensors [8] Irrigation by help of freshwater resources in agricultural areas has a crucial importance. Traditional instrumentation based on discrete and wired solutions, presents many difficulties on measuring and control systems especially over the large geographical areas.

2.2 Automated Irrigation System using WSN and GPRS Module

Automated Irrigation system using WSN and GPRS Module having main goal is that optimize use of water for agriculture crops [1]. This system is composed of distributed wireless sensor network with soil moisture and temperature sensor in WSN. Gateway units are used to transfer data from sensor unit to base station, send command to actuator for irrigation control and manage data of sensor unit. Algorithm used in system for controlling water quantity as per requirement and condition of filed. It is programmed in microcontroller and it sends command through actuator to controlwater quantity through valve unit. Whole system is powered by photovoltaic panels. Communication is duplex take place through cellular network. Web application managethe irrigation through continuous monitoring and irrigation scheduling programming

2.3 Crop Monitoring System based on IoT

WSN The subsequent section introduces the Bluetooth technology. Wireless Sensor network crop monitoring application is useful to farmer for precision agriculture. The application monitors the whole farm from remote location using Internet of Things (IoT). Application works on sensor network and two types of nodes. Energy saving algorithm is used in node to save energy. Tree based protocol is used for data collectionfrom node to base station. System having two nodes one node that collect all environmental and soil parameter value and the other consist of camera to capture images and monitor crops. In this system Environmental changes are not considered forsensor reading.

2.4 Automatic Drip Irrigation System using WSN and Data MiningAlgorithm

Data mining algorithm are used to take decisions on drip irrigation system. Automated drip irrigation system having WSN placed in all over farm and different type of sensors. [9] WSN uses ad hoc network which gives self-configuration and flexibility. Sensor data is given to base station and data is received using zigbee .Data processing is done at base station for decision making. Data mining algorithm is used to take decision on data from sensor to drip. All observation are remotely monitor through web application. This system works on Naïve Bayes algorithm for irrigation control. Algorithm works on previous data set for decision making if any attribute is notfrequent result is zero.

2.5Critical Paper review

2.5.1 Paper 1

The paper discusses the significance of agriculture in India and the challenges posedby dependence on monsoons for water supply. It introduces the concept of utilizing Internet of Things (IoT) technology for smart irrigation, aiming to enhance foodproduction and address water scarcity issues. The system described is microcontroller- based, enabling remote operation via wireless transmission, eliminating concerns about irrigation timing based on crop or soil conditions

Sensors play a crucial role in the system by measuring soil parameters such as moisture, temperature, and air moisture. The decision-making process is controlled by the user, typically a farmer, through a microcontroller. The collected sensor data are transmitted wirelessly to a server database, facilitating automation of irrigation when field conditions indicate reduced moisture and temperature. Farmers receive notifications about the field conditions on their mobile devices periodically.

The paper emphasizes the relevance of this system in areas facing water scarcity, presenting it as a worthwhile and efficient solution. Keywords such as Smart Irrigation, Sensors, Bluetooth communication, and Android highlight the technologicalcomponents involved.

The introduction discusses the need to modernize traditional agricultural practices in India, where a significant portion of the economy depends on agriculture. Waterscarcity, caused by factors like unplanned water use, decreasing groundwater levels, and lack of rains, is identified as a major problem affecting agriculture.

2.5.2 Paper 2

The paper introduces smart irrigation systems, a novel technology utilizing sensors andweather data to optimize crop watering schedules. These systems, through monitoring soil moisture, weather conditions, and plant growth, aim to conserve water and energy while enhancing crop yields. The integration of a mobile application (iOS) facilitates data collection. A computer model processes the sensor data, adjusting irrigation requirements based on factors such as weather forecasts to conserve water during anticipated rain. The paper highlights the potential of smart irrigation systems to transform agriculture by reducing water usage, improving crop yields, and enhancing overall efficiency. Moreover, the systems can be integrated with technologies like weather forecasting and precision agriculture for further advancements.

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CHAPTER 3

PROBLEM DESCRIPTION

3.1 Problem Statement

In the case of traditional irrigation system water saving is not considered. Since, the water is irrigated directly in the land, plants under go high stress from variation in soil moisture, therefore plant appearance is reduced. The absence of automatic controlling of the system result in improper water control system. The major reason for these limitations is the growth of population which is increasing at a faster rate. At present there is emerging global water crisis were managing security of water has become a serious job. This growth can be seen in countries which have shortage of water resources and are economically poor, thus a serious problem in agricultural area. So we want to Design a Smart Irrigation support system that operate automatically by sensing moisture content of the soil and sending the values to a data store comparing it and returning appropriate information to the farmers using app.

The agricultural sector faces significant challenges related to water management, which are exacerbated by climate change, population growth, and the increasing demand for food. Traditional irrigation methods often result in water wastage due to over-irrigation, inefficient water distribution, and lack of real-time monitoring. This inefficiency not only depletes vital water resources but also affects crop health and yields, leading to economic losses for farmers. Additionally, manual irrigation processes are labor-intensive and prone to human error, further complicating efficient water management.

Causes of Water Scarcity:

a) Climate Change: Rising temperatures, changing precipitation patterns, andincreased frequency of extreme weather events contribute to water scarcity by altering the availability and distribution of water resources.
b) Population Growth: Rapid population growth increases water demand fordomestic, agricultural, and industrial purposes, exceeding the available water supply.
c) Inefficient Water Management: Poor water governance, inadequate infrastructure, and wasteful practices in water use and management exacerbate water scarcity.
d) Pollution: Water pollution from industrial activities, agriculture, and inadequate sanitation systems contaminates water sources, making them unfit for use.

Unequal Distribution of Water:

a) Geographical Factors: Natural variations in rainfall, surface water, and groundwater resources lead to spatial disparities in water availability, with arid andsemi-arid regions being more prone to water scarcity.
b) Economic Factors: Wealthier communities and industries often have better access to water resources due to their financial capacity to invest in infrastructure and technology.
c) Social Factors: Marginalized and disadvantaged populations, including rural communities and informal settlements, often face limited access to clean water and sanitation services.
d) Political Factors: Unequal distribution can result from political decisions,corruption, and conflicts over water resources, leading to disadvantaged communities and regions being neglected.

Impacts of Water Scarcity and Unequal Distribution:

a) Human Health: Insufficient access to clean water and sanitation facilities increases the riskof waterborne diseases, leading to illness, mortality, and reduced quality of life.
b) Agriculture and Food Security: Water scarcity hampers agricultural production, reduces crop yields, and limits livestock grazing, resulting in food insecurity and economic instability.
c) Ecosystems: Reduced water availability affects ecosystems, leading to habitat degradation, loss of biodiversity, and disruption of ecological balance.
d) Socioeconomic Challenges: Water scarcity can exacerbate poverty, trigger migration, and contribute to social conflicts over limited water resources

3.2 Our Solution

The solution for smart irrigation involves the integration of Internet of Things (IoT) technology to create an efficient and automated system. Here are key components and features of the smart irrigation solution:

- **Sensor Network:** Deploy soil moisture sensors, temperature sensors, and weather sensors in the agricultural field. These sensors continuously collect real-time data on soil conditions and weather parameters.
- **IoT Connectivity:** Connect the sensors to a central system through IoT connectivity.

This allows seamless communication and data transmission between the sensors and the central control unit.

- **Centralized Control Unit:** Utilize a central control unit, often a microcontroller or computer, to process the data received from sensors. Implement algorithms that analyze soil moisture levels, temperature, and weather forecasts to determine optimal irrigation schedules.
- **Automated Actuators:** Integrate actuators, such as solenoid valves, to automate the irrigation process. Based on the analysis from the central control unit, these actuators regulate the flow of water to the crops, ensuring precise and efficient irrigation.
- **Wireless Communication:** Implement wireless communication protocols, such as Bluetooth or Wi-Fi, to enable remote monitoring and control. Farmers can access the system through a user-friendly interface, possibly a mobile application, to check field conditions and adjust irrigation settings.
- **Data Analytics:** Incorporate data analytics tools to derive insights from the collecteddata. This can include historical trends, predictive analysis, and recommendations for optimizing irrigation practices over time.
- **Weather Forecast Integration:** Integrate real-time weather forecasts into the system. If rain is predicted, the system can automatically reduce or pause irrigation to prevent overwatering and conserve water resources.
- **Energy-Efficient Infrastructure:** Design the system with energy efficiency in mind.Use solar power or other energy-efficient sources to reduce the environmental impact and operational costs.
- **Scalability:** Ensure the system is scalable to accommodate varying field sizes and types of crops. This allows flexibility for farmers with different agricultural needs.
- **Alerts and Notifications:** Implement an alert system to notify farmers about critical conditions, such as low soil moisture levels or extreme weather events. Timely notifications empower farmers to take immediate action.
- **Energy Efficiency**: The system is designed to be energy-efficient, incorporating solar panels and low-power components to reduce energy consumption. This not only lowers operational costs but also supports sustainable farming practices by minimizing the environmental impact.
- **Scalability and Customization**: The smart irrigation system is scalable and can be customized to fit different farm sizes and types of crops. Whether for small-scale farms or large agricultural enterprises, the system can be tailored to meet specific needs and conditions, providing a versatile solution for diverse farming contexts.
- **Remote Monitoring and Management**: Our solution includes wireless communication modules, such as Wi-Fi or Zigbee, enabling data transmission to a central server. Farmers can remotely monitor and control the irrigation system through a user-friendly interface accessible on smartphones or computers. This feature allows for convenient management and quick response to changing conditions, even from a distance.

3.3 Features

A Smart Irrigation System using IoT incorporates advanced features to optimize water usage, enhance agricultural productivity, and enable efficient resource management. Key features of such a system include:

- **Soil Sensors:** Integration of soil moisture, temperature, and humidity sensors to provide real-time data on the environmental conditions of the agricultural field.
- **Wireless Connectivity:** Utilization of IoT devices and wireless communication protocols (e.g., Wi-Fi or Bluetooth) for seamless data transmission between sensors, actuators, and the central control system.
- **Data Analytics:** Implementation of data analytics algorithms to process sensor data, enabling intelligent decision-making based on factors such as soil moisture levels and crop water requirements.
- **Automated Irrigation:** Integration of actuators and control valves for automated irrigation, allowing precise control over water delivery based on sensor feedback.
- **User Interface:** Development of a user-friendly interface, accessible through web interfaces or mobile applications, empowering farmers to monitor field conditions, setirrigation schedules, and receive alerts.
- **Mobile Application:** Creation of a mobile application compatible with both Androidand iOS platforms, providing farmers with remote access to monitor and control irrigation processes.
- **Cloud-Based Data Storage:** Use of cloud-based platforms for storing and managing sensor data, facilitating accessibility from anywhere with an internet connection.
- **Real-time Notifications:** Push notifications to alert farmers about critical changes in soil conditions, irrigation status, or any anomalies that require attention.
- **Weather Integration:** Integration with weather forecasting services to incorporate weather data into irrigation decision-making, adapting schedules based on forecasted conditions.
- **Energy Efficiency:** Integration of renewable energy sources, such as solar panels, to power IoT devices, ensuring a sustainable and energy-efficient operation.
- **Security Measures:** Implementation of security protocols to safeguard the system from unauthorized access, ensuring the integrity and confidentiality of data.

These features collectively contribute to a smart irrigation system that maximizes water efficiency, minimizes environmental impact, and empowers farmers with intelligent tools for precision agriculture.

3.4 Future Scope

The future scope of Smart Irrigation Systems using IoT is poised for significant advancements, driven by the continuous evolution of technology and the urgent need for sustainable agriculture. The integration of cutting-edge technologies promises to revolutionize the way water resources are managed in farming.

The incorporation of Artificial Intelligence (AI) and Machine Learning (ML) is expected to enable more sophisticated decision-making processes. These systems will learn from historical data, weather patterns, and crop characteristics to autonomously optimize irrigation schedules, maximizing resource efficiency and crop yields.

The deployment of drones equipped with advanced sensors and the integration of remote sensing technologies will provide a comprehensive and real-time view of field conditions. This aerial perspective allows for more accurate and timely decision-making, particularly in large agricultural landscapes.

The advent of 5G connectivity will facilitate faster and more reliable communication between IoT devices, ensuring seamless data exchange even in remote areas. This will contribute to more responsive and agile smart irrigation systems.

Blockchain technology is likely to be employed for enhancing data security and transparency within the IoT network, ensuring the integrity of information related to irrigation schedules, sensor readings, and overall farm management.

Moreover, smart irrigation systems are expected to integrate with broader smart city initiatives, promoting holistic urban and rural development. The development and adoption of standardized IoT protocols will further encourage interoperability between devices and systems, fostering a cohesive ecosystem for smart farming technologies.

As these advancements unfold, the future of smart irrigation systems using IoT holds the promise of global scalability, economic impact, and sustainable agricultural practices, addressing critical challenges such as water scarcity and food security on a broader scale. Continuous research, technological innovation, and collaborative efforts are essential to realize the full potential of these intelligent irrigation solutions.

CHAPTER 4

PROPOSED WORK

4.1 Data collection and preparation

In the development of a smart irrigation system, the initial stages revolve around data collection and preparation. This process begins with the strategic deployment of sensors across the field. Sensors such as soil moisture sensors and weather stations are strategically positioned to gather pertinent environmental data. Additionally, satellite imagery might be employed to provide a broader perspective on environmental conditions. Once installed, sensors undergo calibration to ensure the accuracy of their readings. This calibration process might involve adjusting sensor settings or cross-referencing readings with ground truth measurements.

Simultaneously, systems for data logging are established to record sensor data at regular intervals. Whether through direct connections to a central data logger or wireless transmission to a cloud-based platform, data is meticulously logged with synchronized timestamps to maintain temporal consistency.

Following data collection, the focus shifts to data preparation. This stage involves cleaning the collected data to remove noise, outliers, and errors that could compromise accuracy. Techniques such as filtering, smoothing, and interpolation are employed to refine the dataset. Data integration is the subsequent step, wherein information from various sensors and sources is merged to create a comprehensive dataset. This integration process aligns data spatially and temporally to facilitate subsequent analysis. Feature engineering is then employed to extract relevant insights from the raw data. Derived features, such as evapotranspiration rates or soil moisture trends, are computed to providevaluable inputs for analysis and decision-making.

Normalization and scaling techniques are applied to ensure that all features are on a consistent scale, optimizing the performance of machine learning algorithms. The dataset is further divided into training, validation, and testing sets to facilitate model development and evaluation. In some cases, data augmentation techniques may be utilizedto enhance the dataset's robustness. Synthetic data points or perturbations may be generated to simulate variations and expand the dataset.

Through meticulous data collection and thorough preparation, the foundation is laid for the development of a robust and effective smart irrigation system, capable of making informed and precise irrigation decisions.

4.2 Functionalities

In a smart irrigation system, functionalities are designed to optimize waterusage, improve crop yield, and minimize resource wastage. These systems typically encompass a range of capabilities tailored to the specific needs of agricultural operations:

1. **Real-time Monitoring**: Smart irrigation systems employ sensors to continuously monitor key environmental parameters such as soil moisture levels, weather conditions, and crop health indicators. This real-time monitoring enables timely intervention and adjustment of irrigation schedules based on current conditions.
2. **Data Analysis and Decision Support**: Collected sensor data is analyzed using algorithms and models to derive actionable insights. Machine learning techniques may be utilized to predict future soil moisture trends, assess crop water requirements, and identify optimal irrigation strategies. Decision support tools provide farmers with recommendations for irrigation scheduling,helping them make informed decisions to maximize crop productivity.
3. **Automated Irrigation Control**: Smart irrigation systems feature automated control mechanisms to regulate water delivery to crops. Based on real-time sensor data and predictive analytics, irrigation controllers adjust wateringschedules, duration, and volume to meet the specific needs of each crop and soil type. This automation minimizes water wastage and ensures efficient water use.
4. **Remote Monitoring and Control**: Many smart irrigation systems offer remote monitoring and control capabilities, allowing farmers to access systemdata and control irrigation operations from anywhere via web-basedinterfaces or mobile applications. This remote accessibility enables farmers torespond promptly to changing conditions and manage irrigation activitiesconveniently.
5. **Integration with Weather Forecasts**: Smart irrigation systems often integrate with weather forecast services to incorporate future weather predictions into irrigation planning. By considering upcoming rainfall, temperature changes, and humidity levels, these systems adjust irrigation schedules preemptively to optimize water use and minimize waterlogging or drought stress.
6. **Alerts and Notifications**: Smart irrigation systems can generate alerts and notifications to inform farmers of critical events or anomalies detected in the field. Alerts may include notifications of low soil moisture levels, equipment malfunctions, or adverse weather conditions, allowing farmers to take corrective action promptly.
7. **Water Conservation Features**: To promote sustainable water use, smart irrigation systems may include features such as drip irrigation, soil moisture- based irrigation scheduling, and water recycling systems. These featureshelp conserve water resources while maintaining or improving crop yields.

4.3 Architecture Diagram

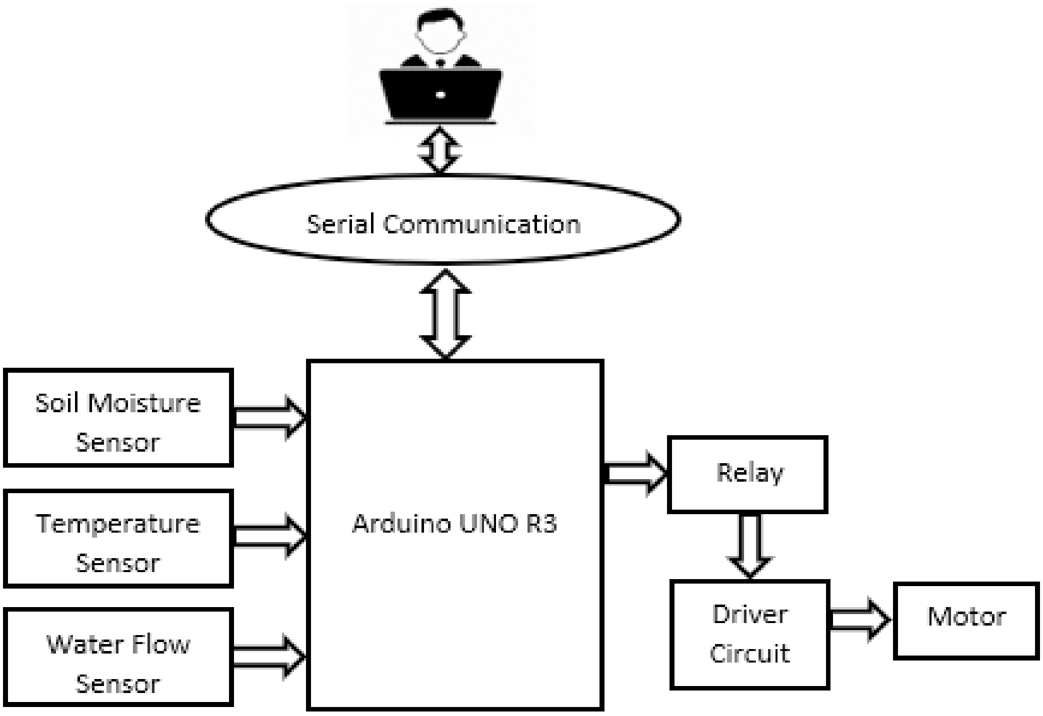

Fig.2 The smart irrigation monitoring system architecture.

Currently, agriculture is encountering many issues due to the challenges of sustainable water resource system design. A smart irrigation system has been proposed in order to support farmers in overcoming their daily hardships. In this system design, we intend to automate the irrigation of the mint by monitoring the soil state of the plant vase. Wehave integrated soil moisture, temperature, and flow sensors with the input pins of the Node MCU and the relay module connected to the water pump to collect hourly measuresin the CSV file via serial communication.

4.4 Use Case Diagram

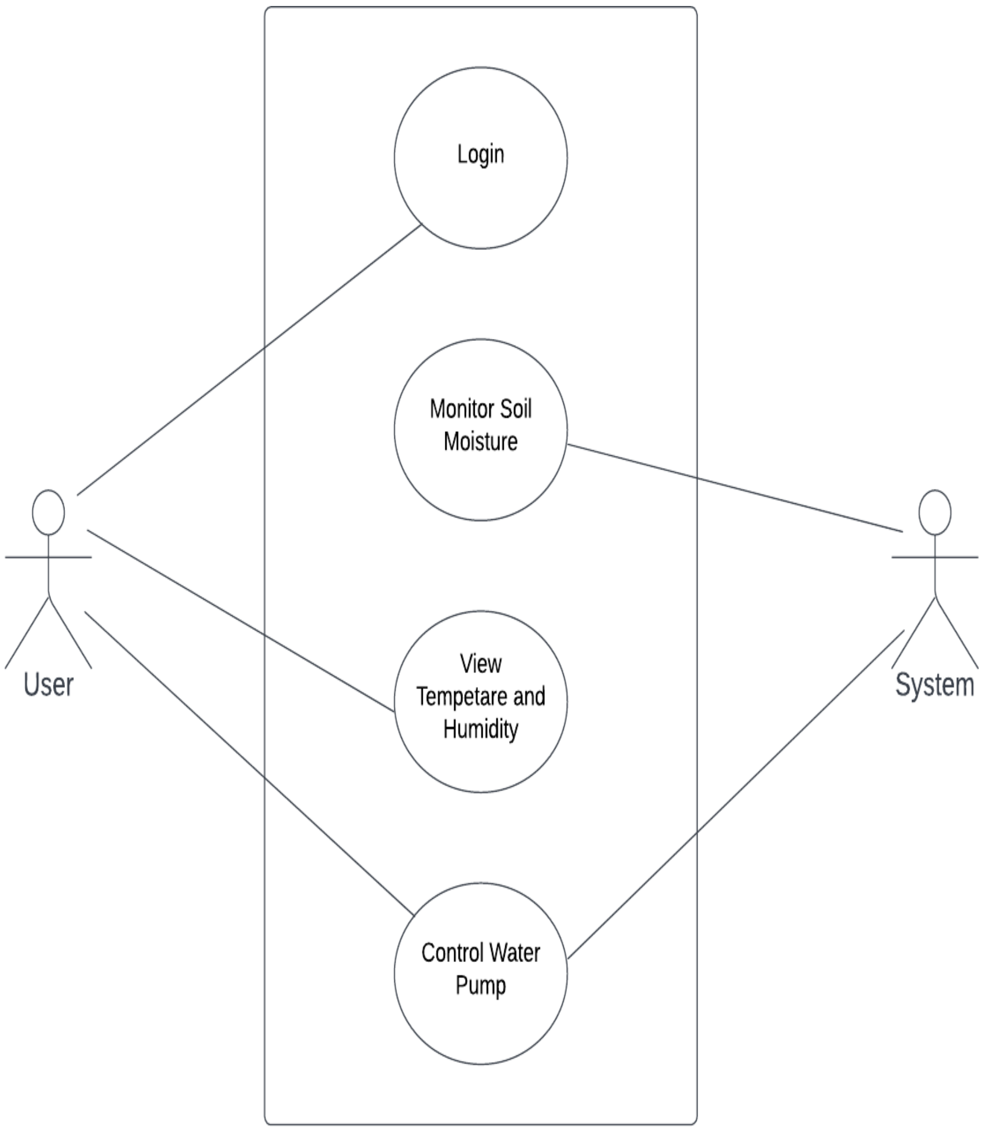

Fig.3 Use Case diagram

4.5 Flow Chart

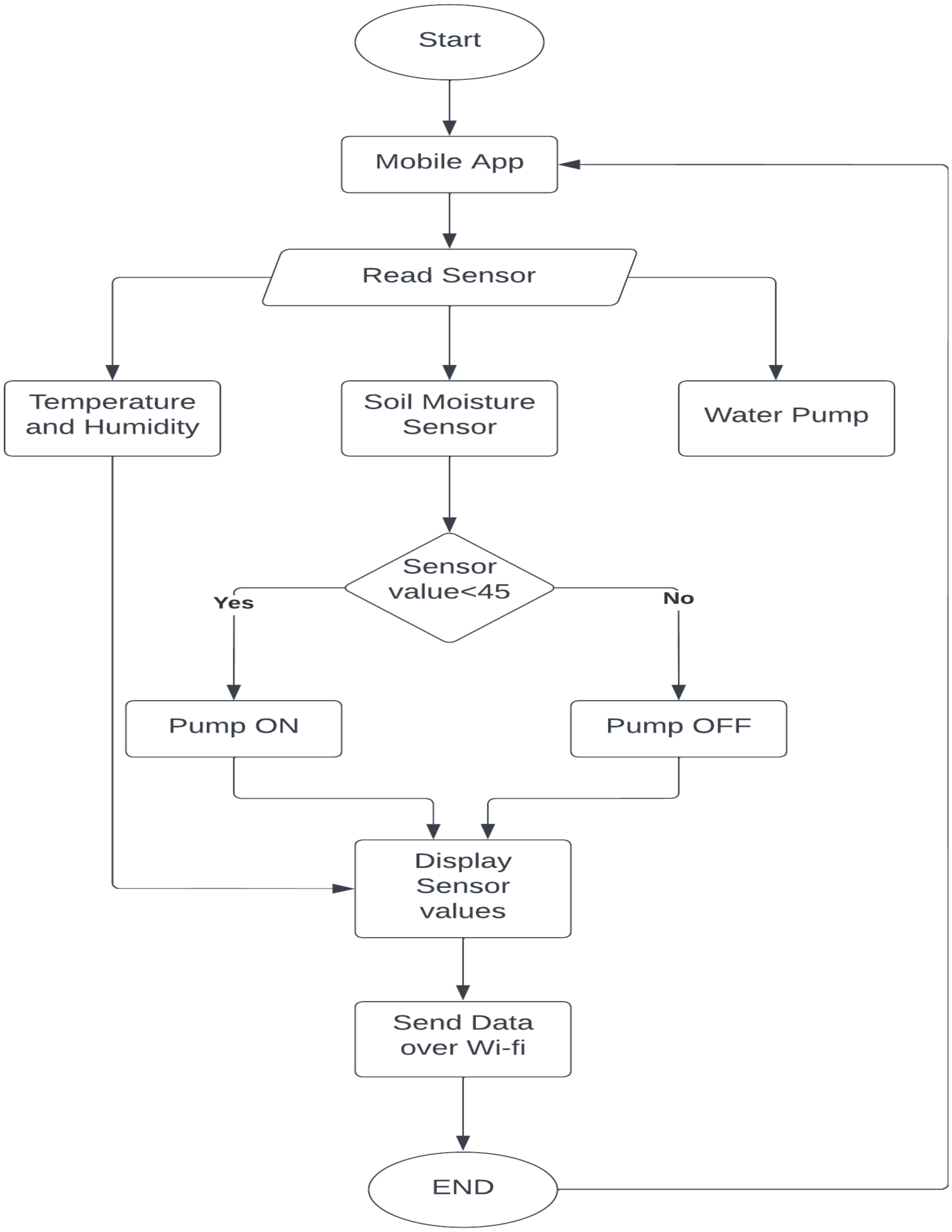

Fig.4 Flow chart

4.6 Circuit Diagram

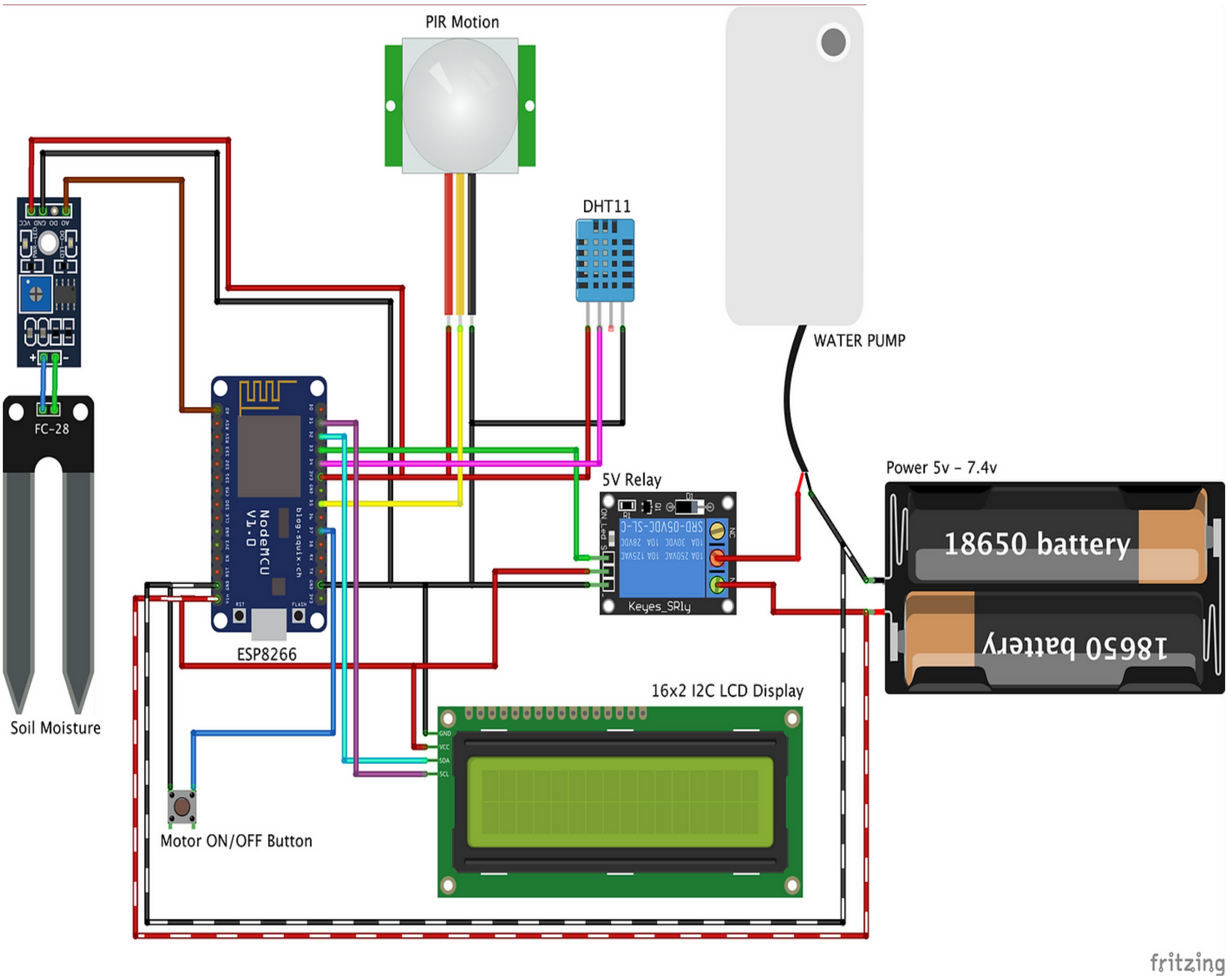

Fig.5 Circuit Diagram for smart irrigation system

In the circuit diagram presented in (Fig.5), we have integrated resistor of (4.7K Ohms)with the color codes of Yellow, Violet, Red, and Golden between the digital data pin and the VCC (5V Pin) of the one wire waterproof temperature sensor (DS18B20) injected in the field. We have also integrated the soil moisture sensor injected into the soil of the mint vase, the submersible water pump (3.3-5V), the water flow sensor "YF- S201" with (water pressure <1.95), and a working range of (1- 30L/min), and a WH Battery (5V) connected to the Node MCU using the (9V/5V) Battery Adapter present in (Fig. 6). To collect the data, we used the serial monitor by connecting the Node MCUto the computer via a USB cable.

CHAPTER 5

IMPLEMENTATION AND RESUL

5.1 Working

A smart irrigation system operates through an intricate process that combines data acquisition, analysis, and decision-making to optimize water usage and enhance agricultural productivity.

At its core, the system relies on a network of sensors strategically deployed throughoutthe agricultural field. These sensors continuously monitor key environmental variables such as soil moisture levels, temperature, humidity, and weather conditions. The collecteddata is then transmitted to a central processing unit, where it undergoes thorough analysis. Through sophisticated algorithms and models, the system processes the sensor data to derive actionable insights and make informed decisions regarding irrigation management. Machine learning techniques may be employed to predict future soil moisture trends, assess crop water requirements, and optimize irrigation schedules based on historical data and real-time conditions.

Once the analysis is complete, the system automatically adjusts irrigation parameterssuch as timing, duration, and volume to meet the specific needs of each crop and soiltype. This automated control mechanism ensures that water is delivered efficiently and effectively, minimizing waste and preventing over- or under-watering. Furthermore, smartirrigation systems often feature remote monitoring and control capabilities, allowingfarmers to access system data and manage irrigation operations from anywhere through web-based interfaces or mobile applications. This remote accessibility enables farmers to respond promptly to changing conditions and make adjustments as needed.

By integrating advanced technology with agricultural practices, smart irrigation systems revolutionize traditional irrigation methods, promoting water conservation, enhancing crop yields, and ultimately contributing to sustainable agriculture.

5.2 Work Flow of the system

At first, the water pump is configured to be disabled, then if the sensed values go beyond the threshold values set in the program (soil moisture< field capacity = 360 = 64.80% or temperature > 30°C), it turns ON and irrigates the soil of the mint vase. Whenever the pump is turned ON, the flow sensor restarts measuring the irrigation flow, the horologe sleeps for (5 seconds: configurable), then the measures are recorded again until the soil moisture outperforms the field capacity. This time control allows an optimized irrigation time which optimizes the amount of water flowing to the field by minimizing the water loss that may be related to a long period of irrigation time before restarting the sensing and the threshold verification. In the case where the soil moisture exceeds the configured field capacity level, the pump turns off, and the horologe sleeps for (1 hour) before repeating the iteration. This process can be summarized as follows:

- Step 1: Start.
- Step 2: The system can be initialized on the Node MCU board.
- Step 2: The clock date is initialized on the Node MCU board, and the waterpump is set to OFF.
- Step 3: The soil moisture sensor checks the soil moisture level constantly.
- Step 4: The temperature sensor constantly senses the temperature level.
- Step 5: The water level sensor constantly checks the water level of the motor.
- Step 6: The microcontroller updates the current date and checks for the threshold condition. If the water content level is inferior to the field capacity level(360) of the mint vase, which means that the soil becomes dry or the temperature surpasses (30°C), then the relay that is connected to the Node MCU will turn ON the motor to irrigate the field. The delay is set to (5 seconds) to repeat step 3. Otherwise, if the threshold condition isn't satisfied, the motor will be turned OFF, and the delay will be set to (1 hour) before repeating step 3.

5.3 Implementation

The implementation of a smart irrigation system involves several key steps, from the initial planning and setup to ongoing monitoring and optimization:
Firstly, the system design begins with an assessment of the agricultural environment, including factors such as soil type, crop type, topography, and climate conditions. Based on this assessment, the appropriate sensors and equipment are selected and deployed across the field.

Next, the sensors are installed and calibrated to ensure accurate and reliable data collection. This calibration process may involve adjusting sensor settings or cross- referencing sensor readings with ground truth measurements to validate their accuracy.

Once the sensors are in place and calibrated, data collection begins. Sensor data, including soil moisture levels, temperature, humidity, and weather conditions, is continuously collected and transmitted to a central processing unit for analysis. In the analysis phase, the collected data is processed using algorithms and models to derive insights into soil moisture trends, crop water requirements, and optimal irrigation strategies. Machine learning techniques may be employed to predict future irrigation needs based on historical data and real-time conditions.

Based on the analysis results, the system automatically adjusts irrigation parameters such as timing, duration, and volume to meet the specific needs of each crop and soil type.This automated control mechanism ensures that water is delivered efficiently and effectively, minimizing waste and maximizing crop yield. Throughout the implementationprocess, ongoing monitoring and optimization are essential. Farmers regularly review system performance, analyze data trends, and make adjustments as needed to improve irrigation efficiency and productivity.

Overall, the successful implementation of a smart irrigation system requires careful planning, meticulous installation, continuous monitoring, and adaptive management to ensure optimal results and long-term sustainability in agriculture.

5.4 Results

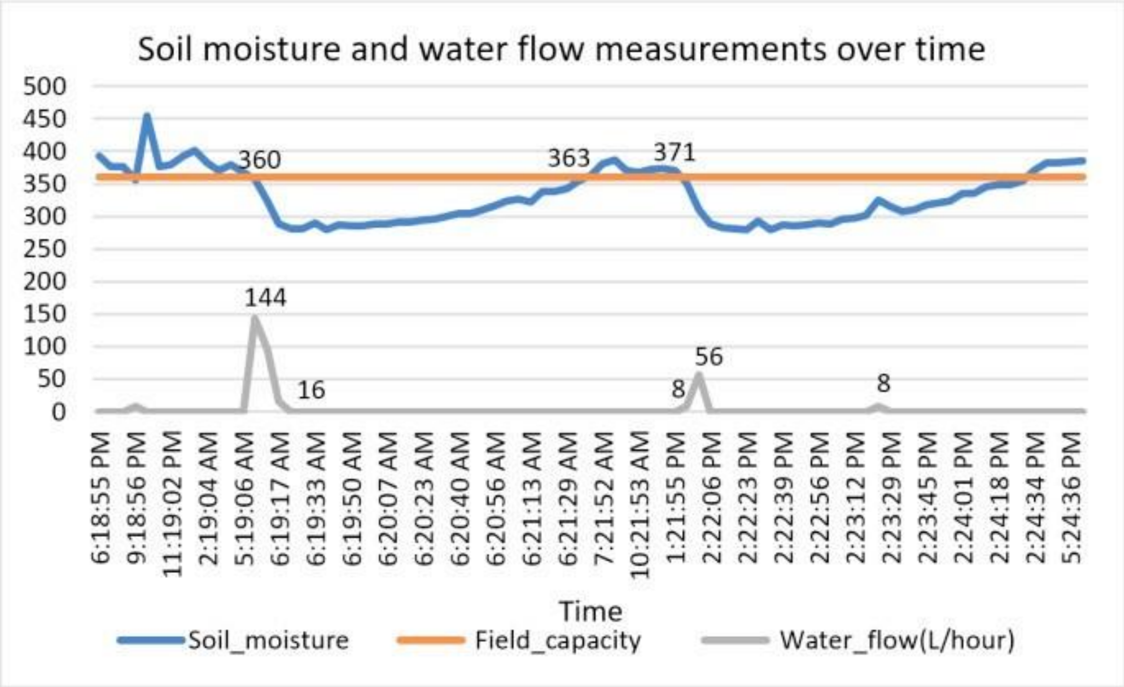

Fig.6 Soil Moisture and Water Flow measurement

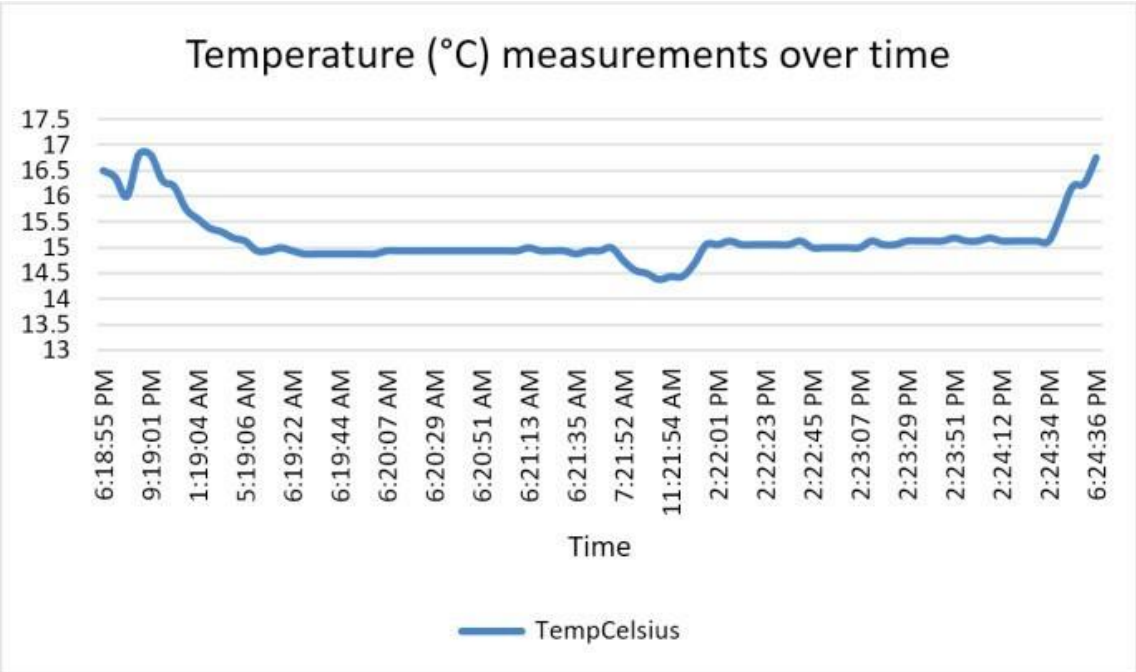

Fig.7 Temperature Fluctuation Diagram

As shown in (Fig.8), the temperature didn't reach the threshold of (30°C), thus when the soil moisture surpassed the field capacity (360) as illustrated in (Fig.8), the pump was turned ON, the water flow reached (144 L/Hour) in (5 seconds) of irrigation and the waterflow measure has been sensed again(144 L/Hour) after a sleep time equal to (5 seconds). The measures are sensed repeatedly after each sleep time of (5 seconds) until the soil moisture exceeds the field capacity threshold (363 > field capacity), then the pump is turned OFF and the measures are recorded again after a sleep time equal to(1 hour). (Fig.8)shows the temperature fluctuations.

Moisture, Temperature, Humidity content of the soil is displayed through blynk app as shown in the below figure.

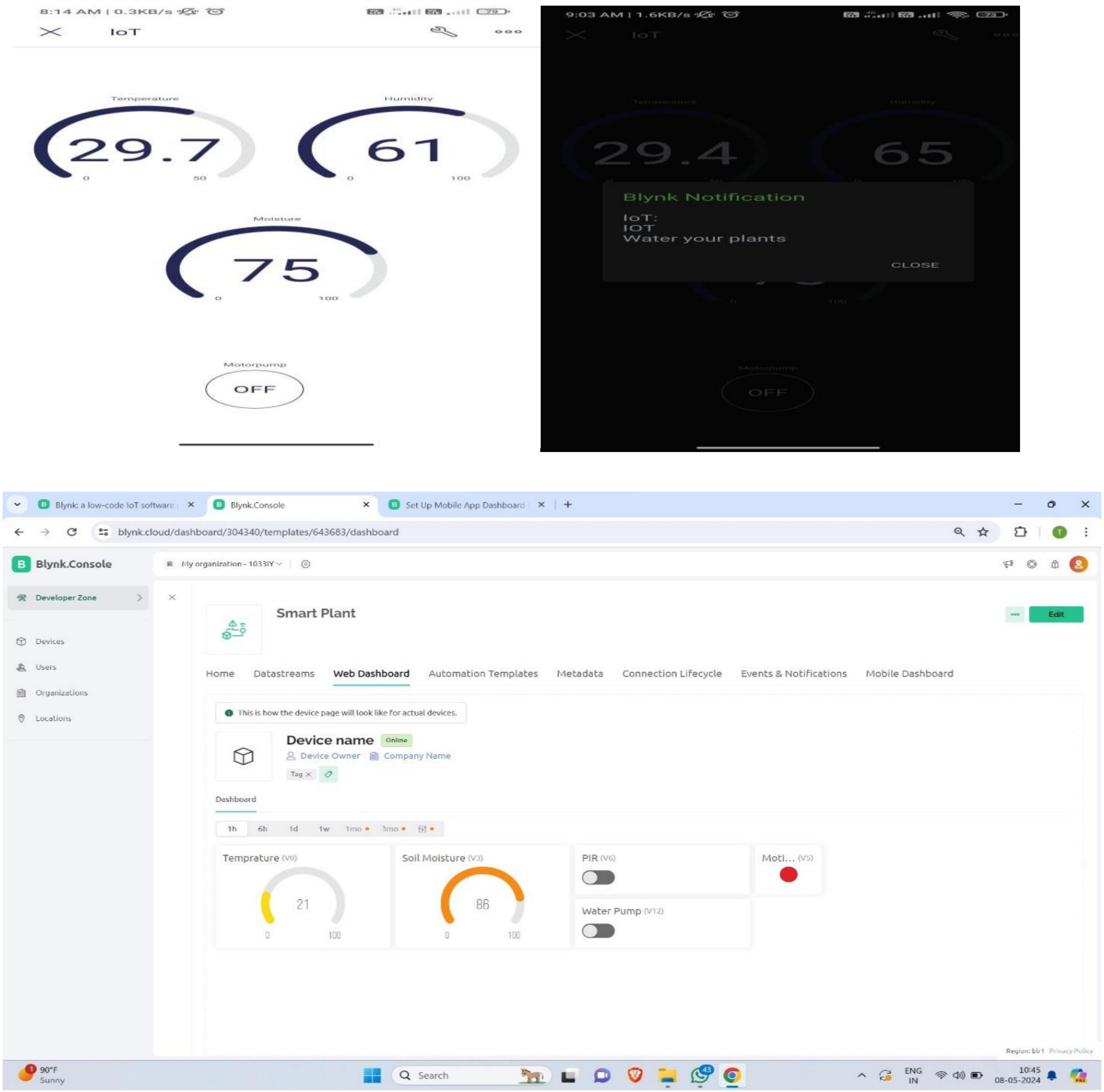

Fig.8 Application Reading

CHAPTER 6

TOOLS AND TECHNOLOGY

6.1 Soil moisture sensor

The soil moisture sensor presented in (Fig.9): characterized by a working range of (0 to 1023 ADC value) used to measurethe moisture content of the mint soil. It consists of two conducting probes that can detect the moisture content in the soil proportionally to the change in resistance between the twoconducting plates.

Fig.9 Soil Moisture sensor

6.2 Temperature sensor (DHT11).

The temperature sensor (DS18B20) present in (Fig.10) is a digital temperature sensor characterized by a working range of (-55 to 125 °C), an accuracy of (+- 5%), integrated with a resistor of (4.7KΩ) with an accuracy of (+-5%), shown in (Fig.10), and employed
to measure the temperature of the mint soil.

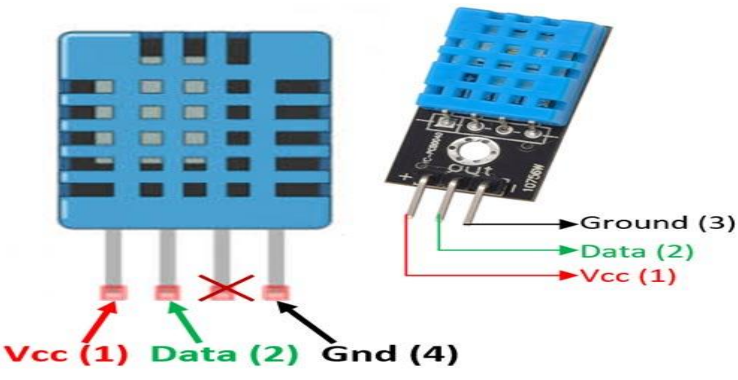

Fig.10 Temperature sensor

6.3 Water flow sensor

The Sea YF-S201 water flow sensor illustrated in (Fig.12) is characterized by a water pressure inferior to 1.95, and a working range of (1-30L/min), and is connected to the pipe of the submersible water pump shown in (Fig.11) to measure the water flow. The water flow sensor generates an electric pulse with every revolution through its integratedmagnetic hall effect sensor that is sealed off from the water and allows the sensor to staysafe and dry. The water pump is a direct current (DC) motor, belonging to a class of rotary electrical motors that generate mechanical energy from electrical energy.

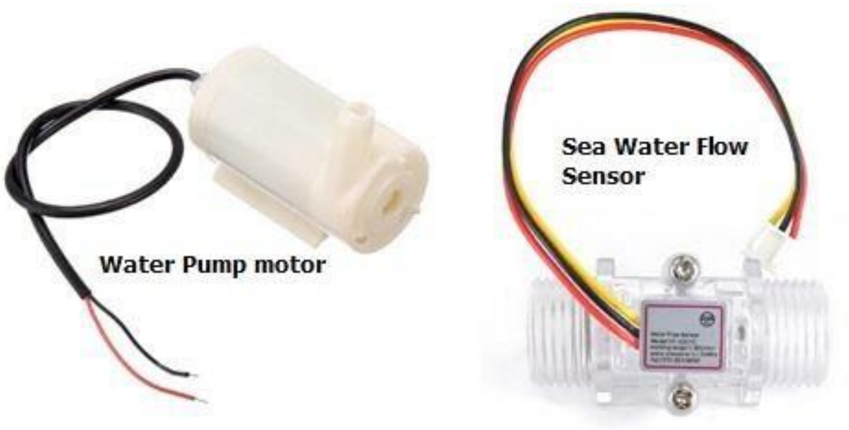

Fig.12 Water Pump

6.4 Node MCU board

The Node MCU, shown in (Fig.13), is a microcontroller board based on the ATMEGA 328P, which includes 32kB of flash memory for code storage. Its panel has 14 digital pins forinputand output, 6 analog pins for input, a reset button, USB, a (16 MHz) quartz crystal, and an ICSP circuit. Usually, Node MCUsoftware is used for programming the Node MCU board.

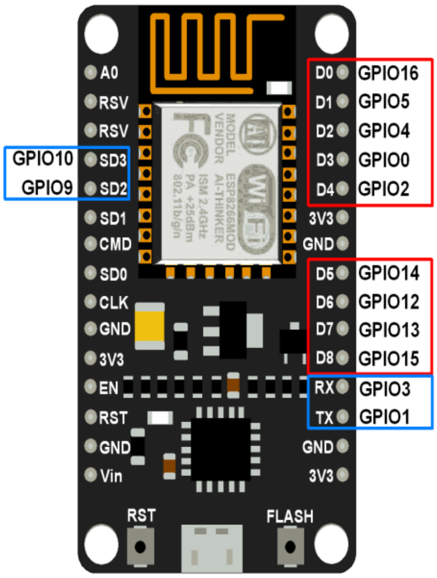

Fig.13 Node MCU

6.5 Relay Module

Relay module Shown in (Fig.14) is an electrically operated switch which is employed in controlling a circuit through a distinct low-power signal. They are even used to protect electrical circuits from overload by integrating calibrated operating aspects, and sometimes multiple operating coils areused to protect electrical circuits from overload. Asportrayedin (Fig.13) the Node MCU is connected to the water pump motor via the relay. Here, the relay plays the role of switchingthe water pump ON or OFF related to the signal received fromthe Node MCUboard.

Fig.14 Relay Module

6.6 Power supply

Using the power supply illustrated in (Fig.15), we have tested connecting the Node MCUboard to the HW battery (9V) through the (9V/5V) Battery Adapter to supply the circuit with the electrical voltage instead of serial communication to make the system independent.
The Node MCUIDE is an open-source Integrated Development Environment (IDE) written in the Java programming languageand is compatible with Windows, MacOS, and Linux, supporting the "C" and "C++" programming languages based on special code structuringrules and providing an enriched library of wiring schemes, integrating many input and output techniques. The Node MCUsoftware allows smoothly writing and uploading controlling code to any kind of Node MCU board.

Fig.15 Power Supply

6.7 PIR Sensor

A PIR (Passive Infrared) sensor Shown in (Fig.16) is an electronic device used to detect the presence of people or animals by sensing infrared radiation emitted from warm bodies. These sensors work by using a Fresnel lens to focus infrared radiation onto a pyroelectric element, which converts the variations in radiation into electrical signals. When a significant change in infrared radiation is detected, typically due to movement within the sensor's field of view, the sensor's integrated circuit processes the signal and activates an output, which can trigger various actions. PIR sensors are widely used in security systems to detect intruders, in automatic lighting systems to improve energy efficiency, in access control systems to activate doors or devices, in home automation to manage heating or air conditioning, and in industrial settings to monitor worker movement for safety purposes. They offer advantages such as low power consumption, reliability, and ease of installation, though they are limited by a restricted detection angle and sensitivity to temperature variations. Overall, PIR sensors are versatile and reliable, balancing cost, efficiency, and functionality for numerous applications.

Fig.16 PIR Sensor

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

Ultimately, a reliable smart irrigation system based on the Node MCU board was designed. The microcontroller circuit has been deployed using smart sensors to monitor the soil state of the mint plant. This circuit included an Node MCU, a relay, temperature, soil moisture, and water flow sensors, a motor (5v), and a battery. The circuit is fully operating, and wevalidated the effectiveness of this system on a mint vasefor one day of recording. After studying the sensed data consolidated in a CSV file onthe computer via serial communication, we concluded that the irrigation time that is controlled using the configurated repeated sleeping time equal to (5 seconds) and the delay of (1 hour) after turning the pump OFF is quite efficient to optimize water consumption while keeping the mint safe. Therefore, this system employs soil sensing technology to control the irrigation of the soil of the plant, which prevents and overcomes intense or poor irrigation, and it could be a potential tool for farmers to save time and reduce their intervention and cost. Nevertheless, serial communication, limited power battery support, and limited graphic design using consolidated files are still not good choices for long-term monitoring. Hence, investing in remote sensing using Bluetooth or WIFI technology using GPRS modules or other networking or powersupply devices, integrating other smart sensors for precipitation or salinity, and integrating an IoT open-source web platform could be the future perspective of this work.

7.2 Future Work

Looking ahead, future work in the field of smart irrigation systems holds immense promise for advancing agricultural sustainability, productivity, and resilience.
One area of future work involves enhancing the integration of advanced technologies suchas Internet of Things (IoT), artificial intelligence (AI), and data analytics. By leveraging IoT-enabled sensors, drones, and satellite imagery, smart irrigation systems can achieve even greater spatial and temporal resolution in data collection, enabling more precise and dynamic irrigation management. Advanced AI algorithms, including deep learning and reinforcement learning, can further optimize irrigation decision-making by learning from large-scale datasets and adapting to changing environmental conditions in real-time.

Additionally, there is a growing emphasis on developing interoperable and scalable smart irrigation solutions that can be easily deployed and customized to diverse agricultural contexts. Standardized data formats, open-source software platforms, and modular hardware.

components can facilitate interoperability and promote collaboration among stakeholders,including farmers, researchers, and technology providers.

Furthermore, future research efforts should focus on addressing emerging challenges such asclimate change, water scarcity, and food security. Smart irrigation systems can play a crucialrole in mitigating the impacts of climate variability by providing adaptive irrigation strategies that account for changing precipitation patterns, temperature extremes, and water availability.

Moreover, there is a need to explore innovative approaches for sustainable water management, such as incorporating alternative water sources (e.g., recycled water, treated wastewater) and implementing water-saving technologies (e.g., precision irrigation, soil moisture-based irrigation scheduling). These efforts can help reduce reliance on finite freshwater resources and minimize environmental degradation associated with conventionalirrigation practices.

Overall, future work in smart irrigation systems should prioritize interdisciplinary collaboration, stakeholder engagement, and technology transfer to ensure that research outcomes are effectively translated into practical solutions that benefit farmers, communities, and ecosystems. By embracing innovation and collaboration, we can harness the full potential of smart irrigation technology to address pressing challenges in agricultureand promote a more resilient and sustainable food system for future generations.

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