IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.67

Volume 5, Issue 4, February 2025

Soil Moisture Detection

Mst. Adit Sanjay Mokashi[1], Ms. Bhakti Sanjay Patil[2],
Mst. Atharv Mohan Mhatre[3], Prof. Shobhana Gaikwad[4]
Students, Department of Computer Technology[1,2,3]
Lecturer, Department of Computer Technology[4]
Bharati Vidyapeeth Institute of Technology, Navi Mumbai, Maharashtra, India

Abstract: *Efficient water management is a very important ingredient in optimization of irrigation practices and sustainable water utilization in this smart farming age. "Smart Soil Moisture Monitoring and Control System Using an ESP32" is a very new concept towards the automation of irrigation based on real-time soil moisture detection. The system reads data from a soil moisture sensor with the help of an ESP32 microcontroller, analyses moisture levels and drives a water pump to switch on or off. This irrigation system is monitored and controlled remotely via a web-based user interface designed with the help of Platform IO and Wi-Fi Access Point mode. The platform provides real time soil moisture data; allows the users to toggle between manual irrigation mode or automatic irrigation mode; and logs moisture data for further analysis. Primary features of the system include data logging and visualization, where the logs can be downloaded and provide trends of water consumption over time. With SPIFFS (SPI Flash File System), data will be stored adequately; using either ThingSpeak or a custom-made dashboard, interaction will provide developers with a general view of moisture trends and pump activity easily observed in real time. The water conservation technique incorporated by the proposed system minimizes manual intervention and provides optimal irrigation services based on soil condition. Future improvements may include cloud integration, AI predictive analytics, expansion into IoT to enhance decision-making for smart farming applications.*

Keywords: Smart Irrigation System, Soil Moisture Sensor, IoT-Based Agriculture, Remote Pump Control

I. INTRODUCTION

Water shortage and inefficiency in irrigation methods are two prevalent issues of modern agriculture that lead to wastage of water with little yield. Traditional irrigation systems rely heavily on either manual controls or pre-scheduled irrigation, which may not fit the moisture state of the soil and the water requirement of the plant. To solve this problem, the project "Smart soil moisture monitoring and control system using ESP32" proposes an automated irrigation system that will optimize irrigation based on real-time data of soil moisture. The system employs a microcontroller ESP32 connected to a soil moisture sensor to measure the water content in soil. These data that are collected will be processed from a web-based interface where the condition of the soil can be monitored, and switching modes and controlling the water pump can also be performed. The ESP32 will operate in Wi-Fi Access Point mode, meaning that users can connect right away to and access the system without any need to have an external network.
In the project, the SPIFFS (SPI Flash File System) is embedded so that data can be locally logged for being available to users, thus answering the need for data-informed management. Also, a data visualization dashboard is put forward to graphically show trends in soil moisture levels and water consumption, thus helping users know the efficiency of their irrigation efforts. Our project module incorporates automatic control of the water pump, which means that irrigation will only be enabled when the computation of the soil moisture level goes below the default threshold. Real-time alerts and notifications assure that users are kept updated about the system's functions, hence making irrigation management more efficient. Data storage can be further amplified because of incorporating cloud services like ThingSpeak, which fetches and allows remote access to historical trends. This solution will lead to an automated irrigation system that uses real-time soil conditions to curtail the waste of water, reduce operating costs, and foster healthy plant development. The future implementation of such systems could incorporate AI-based predictive analytics for irrigation need forecasts from environmental factors. Adding several IoT sensors will enable the system to meet exigencies like high-end farm

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applications whereby advanced soil moisture tracking will be done. This requirement will be cost-efficient and scalable, indeed making it fit for both smallholder farmers and large agro-business stakeholders. Future improvements may expand into cloud data storage, AI-based irrigation predictions, and additional IoT capabilities that would further optimize irrigation efficiency and sustainability.

II. PROBLEM STATEMENT

Waste Water:

Various forms of wastage arise:

Over-irrigation tends to lead to water runoff and leads to depletion of groundwater reserves. Studies indicate that more than 60% of water used for agriculture is wasted in the form of philosophically inefficient irrigation techniques.

Soil Degradation and Nutrient Loss:

Excess water could leach out nutrients necessary for plant growth, harming crop health. Constantly moist conditions can lead to root rot and fungal infections.

Under-irrigation Crop Failure:

Inconsistent watering creates water stress, which leads to reduced crop yields and lower quality. Certain crop varieties may have specific water requirements, not amenable to casual management.

Slow Manual Operations:

The farmers must go and manually feel the soil for moisture; an imperfect and less than reliable means. It requires many labours to cover a large farm, increasing cost and effort.

Power Consumption and High Cost:

The electric or diesel pump, in usage without proper monitoring, just adds to the wastage of energy. High operational outgo has made it such that small and medium farmers cannot sustain it.

III. LITERATURE SURVEY

Efficient water management for agriculture is of paramount importance for resource conservation and improvement in crop productivity. The use of IoT devices and the ESP32 microcontroller connected to the soil moisture sensors have been extensively studied. The survey presents many research papers that contributed to this field.

Automatic watering system for smart agriculture using the ESP32 platform describes the research that constructed a system that monitored soil moisture, humidity, and temperature over time with the help of an ESP32 microcontroller. The system incorporated wireless and IoT networks which converted conventional agriculture to smart agriculture with an objective to optimize water utilization and food security [1].

IoT-based smart irrigation system using ESP32 is yet another major stride that showcases electronic sensors monitoring of soil moisture. The microcontroller ESP32 is processing the recognized data produced by the sensors and is publishing it to a dedicated webpage for surveillance and control in real-time during irrigation. This link provides improvements in water delivery very specific to crop need [2].

Solar water pumping system control using low-cost ESP32 microcontroller describes a solar-powered automated irrigation system that channels moisture and temperature sensor readings into the ESP32 microcontroller, which in turn drives water pumps based on the real-time data obtained. The use of renewable energy resources makes this approach a very appropriate one for irrigating in a developing region owing to energy-efficient and cost-saving [4].

When it is launched, the "ESP32 Smart and Safe Outdoor Plant Watering System" allows for temperature, humidity, and soil moisture monitoring either on-site or remotely through devices like laptops, tablets, or mobile phones. The system guarantees suitable watering levels with control of power on-off to the water pump to avoid the wrong amount of watering. This would ensure reduced water use and good plant health [4]. 80

An irrigation system based on a smartphone connected with soil, temperature, air humidity, and flow water sensors has been developed in the research "IoT-based Smart Irrigation System Using ESP32." The ESP32 exchanges irrigation information with the Blynk app for storage later purposes and watering control, as well as sensible representation of the readings of the sensors graphically. Irrigation, thus, is triggered when the soil moisture drops below a defined threshold, as verified by the temperature sensor indicating the optimal conditions for irrigation [5]. The approach provided its share of the proper amount to be watered at the right times when the crops required it.

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The "ESP32 Based Irrigation System" lays emphasis on developing an agricultural monitoring system based on the Internet of Things to evaluate soil moisture content and many other parameters. The system consists of soil moisture sensors, water level sensorswhich measure temperature and humidity. These sensors give data to the ESP32 module, controlling the irrigation system and visualizing data in the ThingSpeak cloud platform. This setup allows for efficient water management and run-time monitoring offield condition [4].

All these studies act to demonstrate the combined capacity of integrating ESP32 microcontrollers with soil moisture sensors and IoT technologies toward an automated regime for irrigation, thus moderating water use, which in turn ensures adequate moisture is retained in soil, leading to better yields on crops.

IV. METHODOLOGY

A Smart Irrigation System has been developed to monitor soil moisture in real-time and control pump operation based on moisture content in the soil using an ESP32 microcontroller, soil moisture sensors, and a Wi-Fi-based web interface for remote monitoring, control over the Internet, and data logging and visualization processes throughout to study water efficiency trends.

The approach provides insight into all hardware integration, software development, communication protocols, and data management strategies that were realized in the project.

The principle is to have a functional responsive web browser interface accessible through mobile phones, laptops, and PCs, involving no further applications to install.

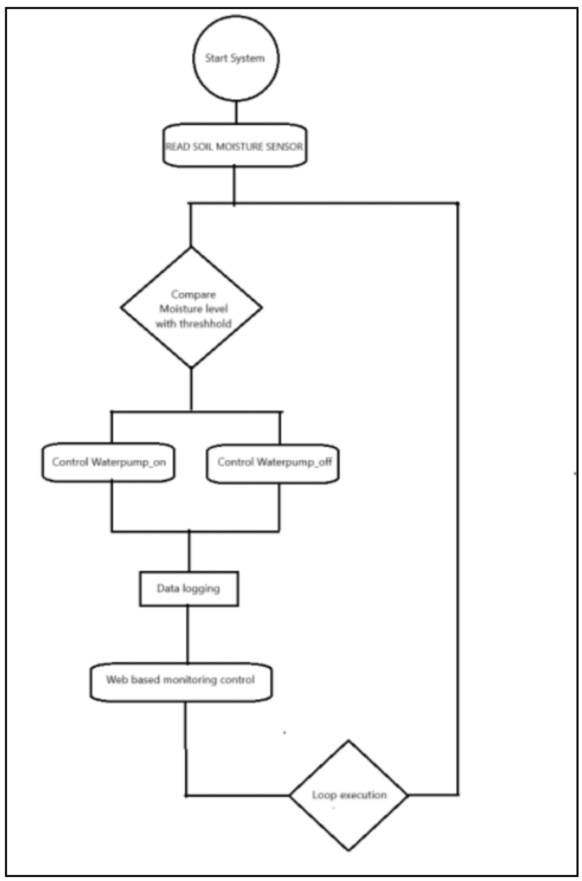

Fig 1.1 General Flowchart

Some of the main features include:

- Real-time soil moisture percentage readings.
- The manual moisture pumps ON/OFF buttons.

- Enables Automatic Irrigation Mode On/Off.
- Data logging to span the history and allow further downloading.

A. Operation:

Running the dashboard on an ESP32 Web server means that the dashboard can be accessed by any user possessing a browser through their local Wi-Fi. Responsive user interface, access via all mobile devices; HTML/CSS/JS development. AJAX keeps the UI alive without page refreshing for the sensor readings to auto-update. The user connects to the ESP32, opens the dashboard, checks out the moisture, and adjusts the settings.

B. User Interaction Process:

- Connect to the ESP32 Wi-Fi.
- Open the web dashboard using a web browser.
- Check the real-time soil moisture readings.
- Can control the pump ON/OFF manually in case of emergency.
- Turn ON Auto-mode for irrigation system operation.
- Would enable logging and access to moisture log files for analysis.

C. Automation logic:

The control logic ensures irrigation operation at optimal soil moisture, therefore controlling water wastage and over-irrigation.

How the automation works:

Real-time ESP32 reading of the soil moisture sensor readings.

The thresholds allow decision statements to run requiring the pump to work or to remain still. For instance, one under 30% would turn ON whenever the soil moisture readings move below 30% to irrigate.

Turn OFF if moisture goes over 50%. By that time, it will stop running if moisture readings cross above 50%.

Hysteresis timer delays control the pump and prevent it from oscillating around unstable conditions.

D. Data Visualization

With greater ease, the moisture levels and the irrigation patterns can now be recognized; various users will therefore rather assess the trends by reference to them instead of entering a raw log into intelligent graphs or charts for analysis.

Most used data visualization includes:

Real-time Moisture Graphs: A graph that is continuously updated, showing the soil moisture levels in real-time.

Historical Moisture Trends: Graphs of moisture levels for the previous days or weeks that may help the user observe any trend.

Pump Activation Timeline: This timeline depicts the time during which the pump was activated and duration for irrigation.

Such tools visualize trends in soil conditions over time, enabling irrigators to optimize their decision-making and push consideration regarding water use.

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V. OVERVIEW

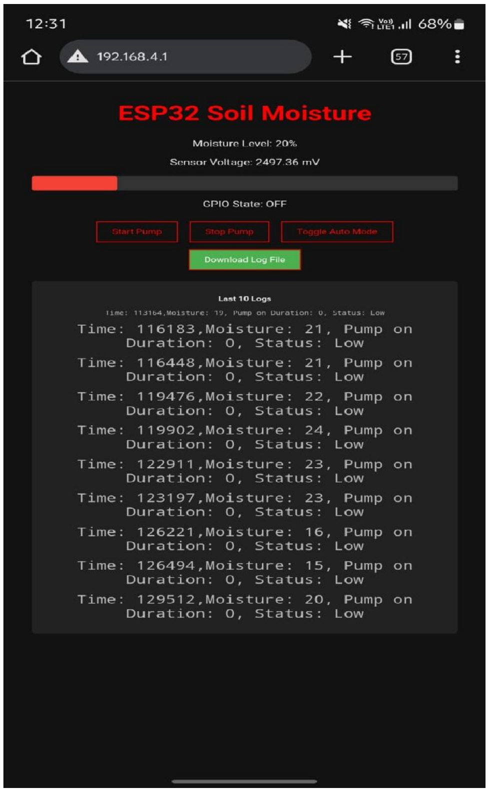

Fig 2.1 Showing Lower Moisture Level

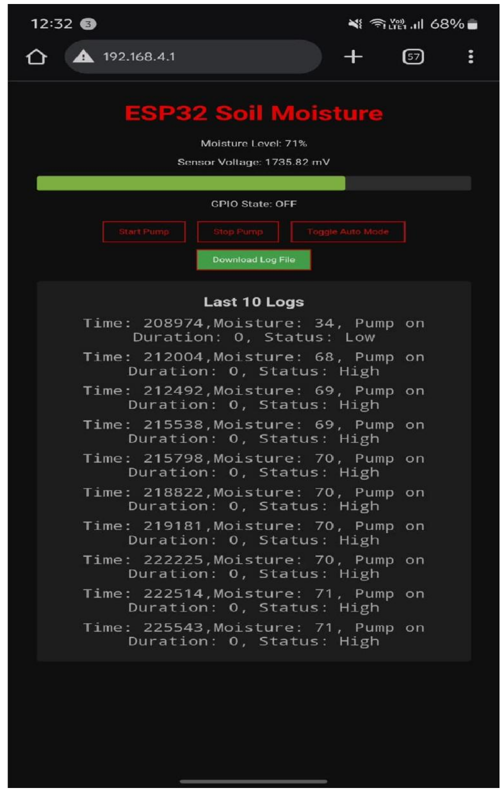

Fig 2.2 Showing High Moisture Level

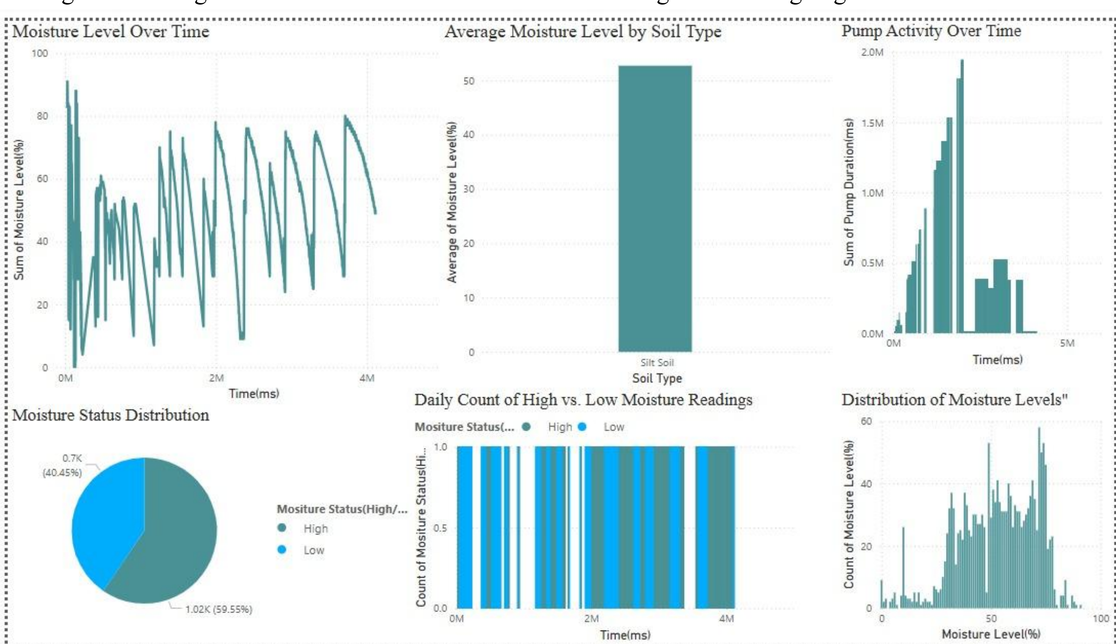

Fig. 3 Data Visualization for Soil Moisture Level

A. The soil moisture varies with time (Top Left Chart).

Type: Line Chart.

Description:

The horizontal axis refers to the elapsed time higher than or equal to zero in seconds and minutes.The vertical axis indicates soil moisture in percentage (%).This is a graph of changing soil moisture conditions over time,with possible causes given watering events, environmental conditions, or naturaldrying of soils.

Observation:

Several peaks and troughs signify that moisture was at certain intervals inclined towards irrigation.The downward trends of soil moisture levels normally indicate either due to evaporation or absorption by plants.

B. Average Moisture Levels According to Soil Type (Top Middle Chart).

Type: Bar Chart.

Description:

On the x-axis, soils of your choice, e.g., silt or clay soil.On the y-axis, this shows the average soil moisture corresponding to that particular soil type.

Observation: It is quite obvious that silt soil has the highest average moisture retention, while all other soils, if any, generally possess various holding capacities.

C. Pump Activity Over Time (Top Right Chart)]

Type: Histogram/Bar Chart

Description: The x-axis refers to time in actual timestamps measured in seconds or minutes.The y-axis indicates the time length in number of seconds or number of minutes during which the pump was actually running.

Observation:

Highs are represented on this chart and include pump operation times. The bars are an indication of extended pump runs because of detection of low moisture within the soil. A majority of the bars are smaller in length, indicating that the pumps were not on very often, but the spikes did exist, especially later on, when the corrective adjustments were made by the system.

D. Distribution of Soil Moisture Status (Bottom Left Pie Chart)

Type: Pie Charts

Description:

The pie chart partitions soil moisture status into two categories-"High" and "Low".The actual shapes reflect percentages that refer to the number of each moisture condition's occurrences.

Observation:

From the study, the soil moisture had "High" for only 40.46% of the time and "Low" for 59.54%. This situation depicts soil viscosity overtaking a majority of observations, suggesting that there would be little irrigation needed at that point in time.

E. Daily tally of High and Low Moisture Readings (Bottom Middle Chart)

Type: Bar Chart

Description:

Once more, the x-axis represents time, with actual readings taken in seconds or minutes.The y-axis indicates the actual count for moisture readings recorded in either High or Low.

Observation:

The alternating blue and light-blue bars show periods of high against low moisture during each day. The representation curtails moisture reading variations over daily time cycles.

F. Moisture Distribution (Bottom Right Histogram)

Type: Histogram

Description:

On this histogram, the x-axis represents individual percentages measuring amounts of moisture.Meanwhile, the y-axis represents quintiles corresponding to the recorded moisture levels over particular ranges.

VI. FUTURE SCOPE

A. Cloud-based Remote Monitoring and Control

Currently, the system runs in Wi-Fi Access Point mode, restricting it to local networks. The addition of cloud computing guarantees:

- Global Remote Access: The possibility to connect to AWS IoT, Google Firebase, or ThingSpeak will provide users with real-time monitoring of soil moisture through web or mobile applications; thus, large-scale farmers will be the main beneficiaries.
- Cloud Storage and Backup: Historical moisture and irrigation data will provide a basis for long-term trending to prevent data loss; hence, the decision-making approach will be more rationalized.
- Remote Pump Control: Users can start and stop the pump using a mobile app from far away, thus controlling their farms from further distances.

Implementation Example: ESP32 sends sensor data to Firebase for real-time monitoring.

B. AI-Driven Predictive Irrigation System

AI can aid in increasing irrigation efficiency through:

- Machine Learning for Smart Watering: AI models analyse historical moisture, weather conditions, and soil type to predict when to water to maximize h2o conservation.
- Irrigation Management for Crops: The system modifies the irrigation schedule based on crop needs automatically, e.g., rice paddies receive more frequent watering than drought-resistant crops.
- Live Weather Forecast Integrations: System will take into the live weather APIs and delay irrigation if rain is forecasted or increase irrigation frequency when our weather system indicates high-temperature settings.

Implementation: The ESP32 takes real-time weather and sensor data the AI uses to optimize irrigation schedules.

C. Expansion to Large-scale Smart Farming

Scaling the system to expand for larger fields of crop-growing will mean:

- Multiple Sensor Networks: Deploy multiple sensors to different zones in order to achieve the highest moisture monitoring and individualized irrigation.
- Automated Control for Drip Irrigation: When the system integrates with the drip irrigation system, water will be supplied so that water is put where needed most efficiently.
- Solar water-powered irrigation: Adding solar panels will cause irrigation through solar power where the whole system becomes vegetarian in supremacy! therefore suitable remains viable on any farm regardless of location.

Implementation: LoRaWAN.

VII. CONCLUSION

Water Soils Sampler and Smart Irrigation System based on ESP32 gives real-time and automatic cost-effective mechanism in water conservation for precision farming. The highlight of the project is real-time soil moisture, automation of pump control, and web-based GUI with optimized irrigation at a water loss reduction through evaporation, drainage, runoff, etc.

The ESP32 consolidates the microcontroller which facilitates all stages of reading the sensor readings, the logic operations, and provision of user interfacing through the Wi-Fi dashboard. The irrigation activities and moisture could be logged and archived for possible later comparison and historic analysis. More advanced steps might involve remote cloud-based monitoring and AI-assisted irrigation forecasting as well as smartphone apps that can potentially assist agricultural operations based on the real-time data from the projects.

Key Project Milestones:

- Automation of watering thus decreasing manual labour.
- Live moisture monitoring in soil allowing water-conservation.
- Logging data and data presentation for better irrigation schedules.
- Remote monitoring and control with web interface.
- Large-scale farming use with expandability in future.

The present project is highly likely to promote sustainable farming through saving wastage of water as well as man labour. The utilized IoT-based application is potentially amenable for cloud-based association with AI-advantaged analytic facilities in independent forms toward completely autonomous smart irrigation solutions. Under extended uses, technology in that manner would extensively enhance productivity while decreasing operating expenditure as well as achieving eco-sustainability for agricultural pursuits in full scale.

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