Decentralized IoT Solution for Smart Agriculture Using Edge Computing

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IoT-based smart irrigation management system to enhance agricultural water security using embedded systems, telemetry data, and cloud computing

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IoT-based smart irrigation management system to enhance agricultural water security using embedded systems, telemetry data, and cloud computing

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ABSTRACT

Agriculture, the key sector for food production, faces challenges exacerbated by the growing global demand for food and the scarcity of water resources. Traditional irrigation methods often lead to inefficient use of water, resulting in wastage. Moreover, unpredictable weather conditions and the need to adopt sustainable farming practices are driving us to develop advanced irrigation systems. This paper proposed a smart irrigation management system using new technology like 1) embedded systems, 2) Internet of Things (IoT), 3) telemetry data, 4) cloud computing, communication protocol, and 5) sensors to collect and process real-time data of the smart agriculture. This new technology and intelligent algorithm are used in this paper to improve agricultural practices. The architecture of the proposed scheme comprises three layers: 1) IoT devices, 2) ThingsBoard cloud, and 3) the dashboard, each playing a pivotal role in ensuring seamless data flow, secure communication, and enhanced user interaction. The algorithm orchestrates system operations, incorporating sensor data reading, JavaScript Object Syntax (JSON) payload creation, and secure telemetry data transmission via Hypertext Transfer Protocol (HTTP) protocol to the ThingsBoard cloud. Pump activation decisions are governed by predefined thresholds, preventing an over-irrigation system. The evaluation of system performance involves deploying temperature, humidity, moisture, and water level sensors in a testing field. Further, before data is sent to the cloud, sensor values are calibrated using a functional map. Tests carried out with temperature, humidity, and water level sensors demonstrate the system's dynamic efficiency. By visualizing and analyzing environmental information via ThingsBoard, the results provide real-time data on environmental parameters of the system proposed, improving the efficiency of water use and the sustainability of farming practices. In addition, the system features e-mail notifications for alerts. The integration of e-mail notifications reinforces monitoring and management practices by alerting farm owners and users. This study showcases the efficacy of the proposed paper in enhancing sustainability, water usage, and supporting smart agriculture practices. Further, this paper integrates embedded systems, IoT, cloud computing, and advanced algorithms to optimize and enhance crop productivity and contribute to global food and water security.

Perspective of Cloud Computing

Future Of Cloud Computing

Centralized vs. Decentralized Cloud

Cloud computing's future is a tug-of-war between

- Centralized
- Decentralized

-Tim Berners-Lee (Inventor of the Web)

Berners-Lee introduced Solid, an open-source project aimed at giving individuals control over their data

Future Of Cloud Computing

Centralized vs. Decentralized Cloud

1 The Current State of Cloud Computing (Big Tech Dominance)
Tech giants like **AWS (Amazon), Google Cloud, Microsoft Azure** dominate cloud infrastructure. They provide:

✅ **Scalability** – Businesses don’t need to manage hardware.
✅ **High Reliability** – Strong infrastructure with backups.

Future Of Cloud Computing

Centralized vs. Decentralized Cloud

2️⃣ The Rise of Decentralized & Personal Cloud Servers

- **Personal Cloud Servers** – Individuals/companies hosting their own private cloud (e.g., Nextcloud, Syncthing).
- **Peer-to-Peer Cloud Storage** – Data stored across a network of devices, not in centralized data centers (e.g., IPFS, Storj, Filecoin).

✅ **Full Data Ownership** – No third party controls your files.
✅ **Cost Savings** – "**Avoid expensive cloud subscriptions**" in the long run.
✅ **Better Privacy & Security** – No centralized entity has access to all your data.

Perspective of Web Development

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Web 1.0 vs Web 2.0 vs Web 3.0

Web 1.0 (Static Web) – 1990s to early 2000s

- **Read-Only:** Users could only consume content, not interact with it.
- **Static Websites:** Basic HTML pages with minimal interactivity.
- **Centralized Control:** Content was controlled by website owners, no user-generated content.
- **Examples:** Early Yahoo, Netscape, Britannica Online.

Web 1.0 vs Web 2.0 vs Web 3.0

Web 2.0 (Social & Interactive Web) – 2000s to Present

- **Read-Write:** Users can create and share content (blogs, social media, wikis).
- **Dynamic & Interactive:** Websites became more user-friendly and responsive (AJAX, JavaScript, CSS).
- **User-Generated Content:** Platforms like Facebook, YouTube, Wikipedia, and Twitter thrived.
- **Centralized Platforms:** Tech giants control major platforms, monetizing user data.

Web 1.0 vs Web 2.0 vs Web 3.0

Web 3.0 (Decentralize) – Emerging Trend

- **Read-Write-Execute:** Smart applications with Networks where only users can manage their data and resources on their server.
- **Decentralization:** No centralized servers, Each users will have their own mobile servers that they can carry where ever they want.
- **Companies-Working-On:** Roblox, Google

Abstract

Existing smart irrigation systems face limitations such as dependency on third-party cloud services, inefficient water usage, limited connectivity, and lack of data privacy. These challenges often hinder the effectiveness and scalability of traditional solutions. To address these issues, this project proposes a decentralized smart irrigation system tailored for agricultural fields. By integrating private web-based monitoring and automated irrigation control, the system eliminates reliance on external cloud platforms, ensuring seamless and uninterrupted operation. This approach envisions a future where farmers have full control over their irrigation infrastructure, enabling real-time decision-making and optimizing resource usage. With enhanced autonomy, secure data management, and decentralized operation, it paves the way for more resilient, scalable, and self-sufficient agricultural practices, ultimately promoting sustainability and long-term efficiency in farming.

Problem Statement

Dependency on External Platforms and Data Privacy Concerns

Traditional smart irrigation systems often rely on third-party cloud services for data storage, processing, and decision-making. While this approach enables remote monitoring and control, it raises significant concerns regarding data privacy and security. Previous research on IoT-based irrigation models highlights that storing sensitive agricultural data on external servers exposes it to potential breaches, unauthorized access, and data misuse. Additionally, the reliance on cloud-based platforms increases operational costs and creates dependency on service providers, which can lead to service disruptions if the platform experiences downtime or policy changes. These limitations underscore the need for decentralized solutions that allow farmers to retain control over their data while ensuring secure and efficient irrigation management.

Literature Survey

S.No	Title	Methodology	Merit	Demerit
1.	AUTOMATIC IRRIGATION SYSTEM - Department of Information & Communication Technology Comilla University – [2024]	**Arduino Uno** controls **soil moisture sensors** to automate irrigation. A **relay module** operates a **water pump**, ensuring plants get water only when needed.	• Water-saving • **Efficient Water Control**	• No **Remote Control** or **Monitoring**
2.	Automatic Irrigation System using Soil Moisture Sensor – Link – [2023]	**Arduino Uno** reads **soil moisture levels** and controls a **relay-operated water pump** for **automated irrigation**, reducing water waste and manual effort.	• Simple to implement	• No **Remote Control** or **Monitoring**

Literature Survey

S.No	Title	Methodology	Merit	Demerit
3.	Smart irrigation system based on IoT and machine learning – Science Direct – [2022]	IoT sensors collect **soil, temperature, and rain data**. Machine learning models (**KNN, SVM, Neural Networks**) predict irrigation needs, optimizing **water efficiency and automation** via **Node-RED and MongoDB.**	• Uses **ML model** • Uses **DB**	• No **Remote Control** or **Monitoring** • **Non interactable**
4.	IoT based Smart Irrigation System using Soil Moisture Sensor and ESP8266 NodeMCU – circuitdigest.com link – [2021]	**ESP8266 NodeMCU** reads **moisture, temperature, and humidity**. Data is sent to **ThingSpeak**, and the **pump operates automatically** based on moisture levels.	• Remote **Monitoring** • **More features** sensed • User Friendly	• No privacy [ThingSpeak used] • Only useful for **small lands**

Literature Survey

S.No	Title	Methodology	Merit	Demerit
5.	IoT based Smart Irrigation System – [Electrical Engineering Department, Egyptian academy for engineering and advanced technology] – [2022]	**IoT sensors** monitor soil, temperature, and rain. **ESP32 microcontrollers** process data for **automated irrigation**, controlled via **mobile/web apps** using **MQTT protocol**.	• Remote **monitoring** • Cheaper MC Used	• No privacy [Third party Brokers used]
6.	IoT and Cloud Based Sustainable Smart Irrigation System – E3S Web of Conferences 472 – [2023]	**IoT sensors** monitor soil moisture and weather. **NodeMCU** processes data and controls irrigation via **cloud-based automation**, optimizing water use and enabling remote access.	• Remote **Control** • Cost-saving	• High setup cost • Heavy MC used

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Workplan

- Prepare Ideation
- Create PPTs
- Draft Workplans

0th Review

1st Review

- Connection between Raspberry Pi and Esp32
- Implement detection and pump control
- Complete IoT Physical

- Configure RaspberryPi as Web Server
- Complete Web Development Works
- Document Submission

2nd Review

Methodology

The system consists of a **Raspberry Pi as the master node** and multiple **ESP32-based slave nodes**, each equipped with a **soil moisture sensor and a sprinkler**. These nodes are strategically placed across the field and communicate with the Raspberry Pi using wireless data transmission techniques(Here WiFi is used for Communication).

Every **5 minutes**, the ESP32 nodes measure the soil moisture levels and send the data to the **Raspberry Pi**, which updates it on a **webpage** for the landowner to monitor in real time. When the moisture level drops below a **set threshold**, the **sprinkler automatically activates** and remains on until the soil reaches the required moisture level, ensuring **optimized irrigation**.

This method enables **automated water management**, reducing manual effort and water wastage while providing a **smart, decentralized, and efficient irrigation system**.

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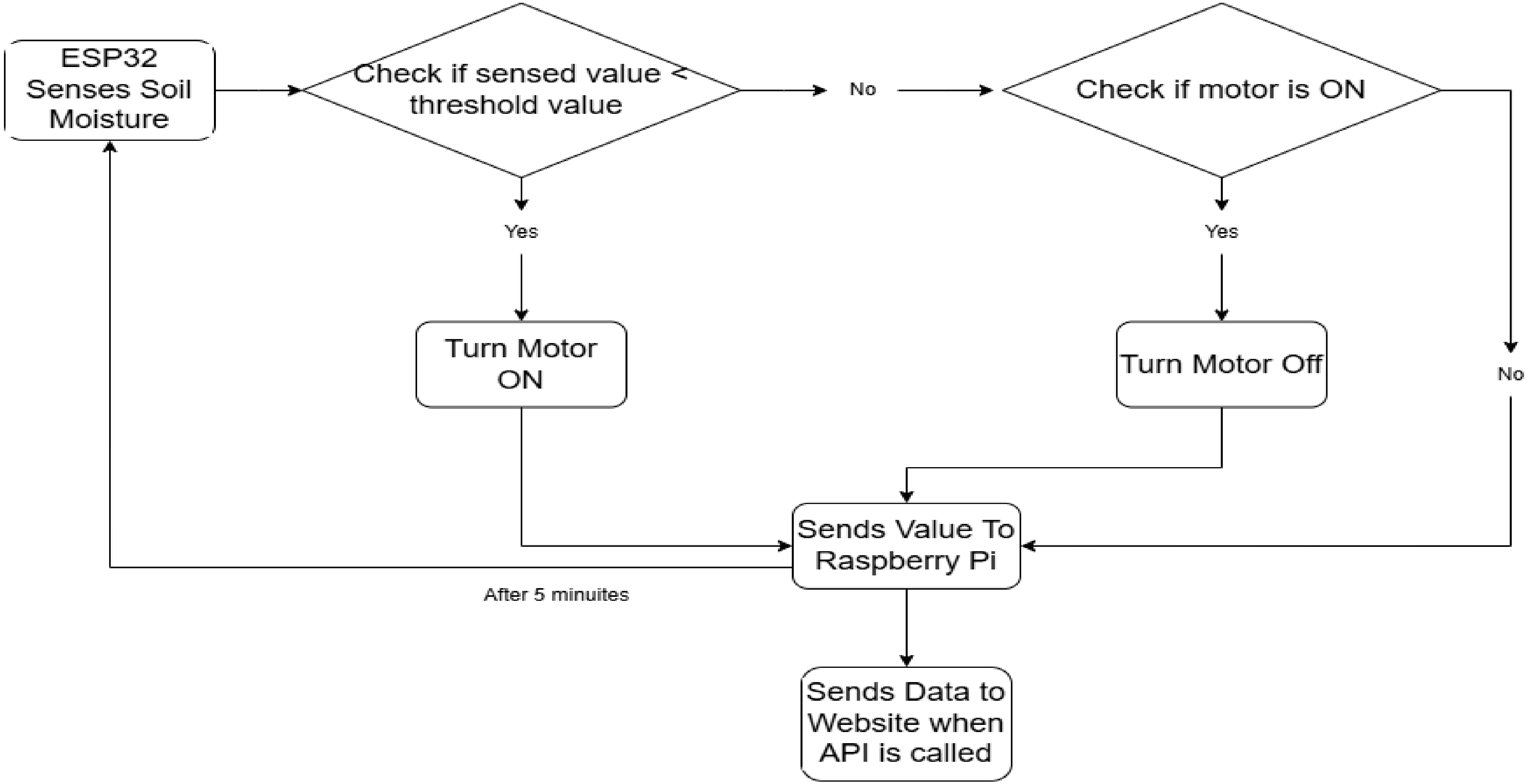
Workflow



Conclusion

The system proposed with decentralized web hosting may lead to the basic version of future cloud computing and web hosting concepts, simplifying futuristic ideas and ensuring data security for users.

Having partially completed the IoT implementation in this review, I will be focusing on the web hosting aspect in the next and final review.

THANK YOU!