**Abstract**

**The integration of smart irrigation systems in agriculture has gained significant momentum, owing to the imperatives of optimizing water usage and enhancing crop productivity. This study proposes an innovative system that amalgamates moisture and ultrasonic sensors, a NodeMCU ESP8266 microcontroller, a relay module, and a pump with varying voltage options, all interconnected via a Firebase database. The system operates by monitoring soil moisture levels and environmental conditions using the sensors, enabling the NodeMCU ESP8266 to control the irrigation process through the relay module and pump. The data is transmitted to the Firebase database, allowing for remote access and analysis through a user-friendly web interface. This approach aims to promote efficient water management, automate irrigation processes, and facilitate real-time monitoring, thereby fostering sustainable agricultural practices and enhancing crop yield.**

**Introduction**

The IoT-based Irrigation System embodies a modern approach to agricultural practices by employing Internet of Things (IoT) technology to revolutionize traditional irrigation methods. This project focuses on the seamless integration of hardware, software, and cloud-based services to create an intelligent and automated irrigation system. The core of this project lies in the convergence of hardware components, specifically the ESP8266 microcontroller, and a moisture sensor, alongside software frameworks like Firebase for data storage and retrieval. By amalgamating these elements, the project aspires to craft an irrigation system capable of real-time monitoring, analysis, and autonomous decision-making regarding watering cycles. Develop an automated irrigation system that optimizes water usage by responding dynamically to soil moisture levels. The system should reduce water wastage while ensuring plants receive adequate hydration. Utilize the capabilities of IoT to gather, store, and analyse data related to soil moisture levels. This data will inform irrigation scheduling, allowing for more informed and precise watering decisions. Integration and Accessibility: Integrate the irrigation system with Firebase, enabling remote access to data and control of the system through a user-friendly web interface. This accessibility promotes ease of monitoring and control for users. Optimization for Plant Health: Strive to create an irrigation system that not only conserves water but also optimizes plant health and growth by maintaining ideal moisture levels tailored to specific plant needs.

**Related Work**

Various studies have contributed significantly to the field of smart irrigation systems powered by the Internet of Things (IoT). Delving into methodologies for efficient water usage[1], while other explores IoT-based systems employing wireless sensor networks, emphasizing sensor functionalities[2]. The next one highlights the advantages of integrating IoT with Firebase for effective data management in smart irrigation[3], followed by next paper, which focuses on the design and utilization of renewable energy in solar-powered IoT-based systems[4]. Offering comprehensive insights and technical perspectives on IoT-based systems, covering technological aspects and emphasizing the role of microcontrollers[5] [6]. Emphasizing advancements in solar-powered systems and offering a review on IoT-based smart agriculture, highlighting key issues and future prospects[7][8]. Investigating automation's impact and specific applications for outdoor plants[11], while next paper explores the effects of drip irrigation systems on water use efficiency in crops[11]. Introduction of IoT-based plant watering systems employing image processing for hydration assessment, whereas some discuss sustainable water management in urban landscapes and review IoT-based smart irrigation technologies integrating cloud computing [12][13][14]. These diverse studies collectively contribute to enhancing our understanding, advancements, and potential applications of IoT-based smart irrigation systems for fostering sustainable agricultural practices.

**Proposed Solution**

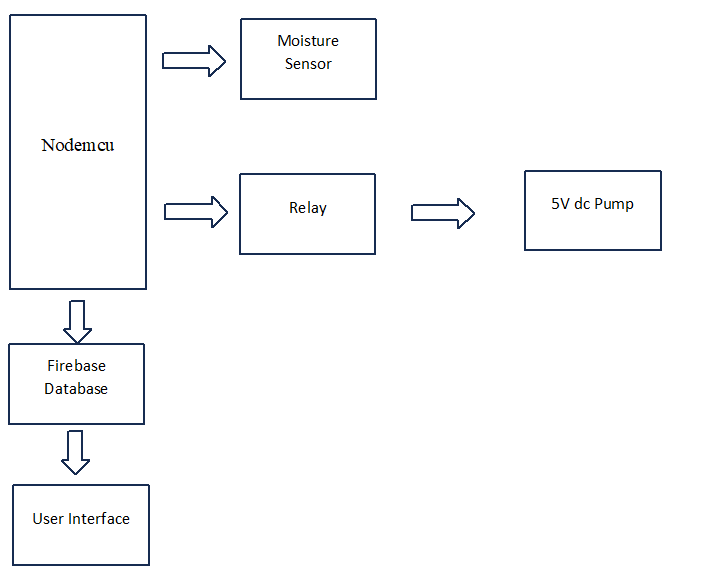
The project addresses several key challenges identified in previous research within the domain of smart irrigation systems driven by IoT technologies. These challenges, as highlighted in prior studies, encompass inefficiencies in traditional irrigation practices, imprecise water management leading to water wastage, and difficulties in adapting irrigation schedules to varying soil moisture levels. Previous works underscore the need for precise irrigation strategies tailored to specific crop needs, especially in regions prone to water scarcity and unpredictable climatic conditions. Additionally, the lack of real-time data on soil moisture and the absence of automated systems for timely irrigation emerge as critical issues impacting agricultural productivity and water conservation efforts.

Our project aims to tackle these challenges by leveraging IoT-based technologies, such as the ESP8266 microcontroller, moisture sensor, relay, and 5V DC pump, to create a responsive and data-driven smart irrigation system. By integrating these components, our system facilitates real-time monitoring of soil moisture levels, enabling informed decision-making for optimized irrigation schedules. This initiative directly addresses the inefficiencies highlighted in previous papers, aiming to minimize water wastage while ensuring adequate hydration for crops. Through automated control mechanisms triggered by the moisture sensor readings, our system seeks to offer a precise and efficient approach to irrigation, aligning water delivery precisely with the crops' requirements. Ultimately, the project endeavours to contribute to sustainable agricultural practices by providing a solution that optimizes water usage, enhances crop yield, and mitigates the challenges outlined in earlier studies concerning irrigation inefficiencies and water conservation in agriculture. The main contribution of this paper is proposed below:-

1. To get maximum efficiency using solar power.
2. To understand and analyse the need for water for the upliftment of crops using moisture sensors and nodemcu.
3. To make the irrigation system automated and hassle-free for farmers with the help of Firebase and a user-friendly website.

**System architecture**

**Block Diagram**

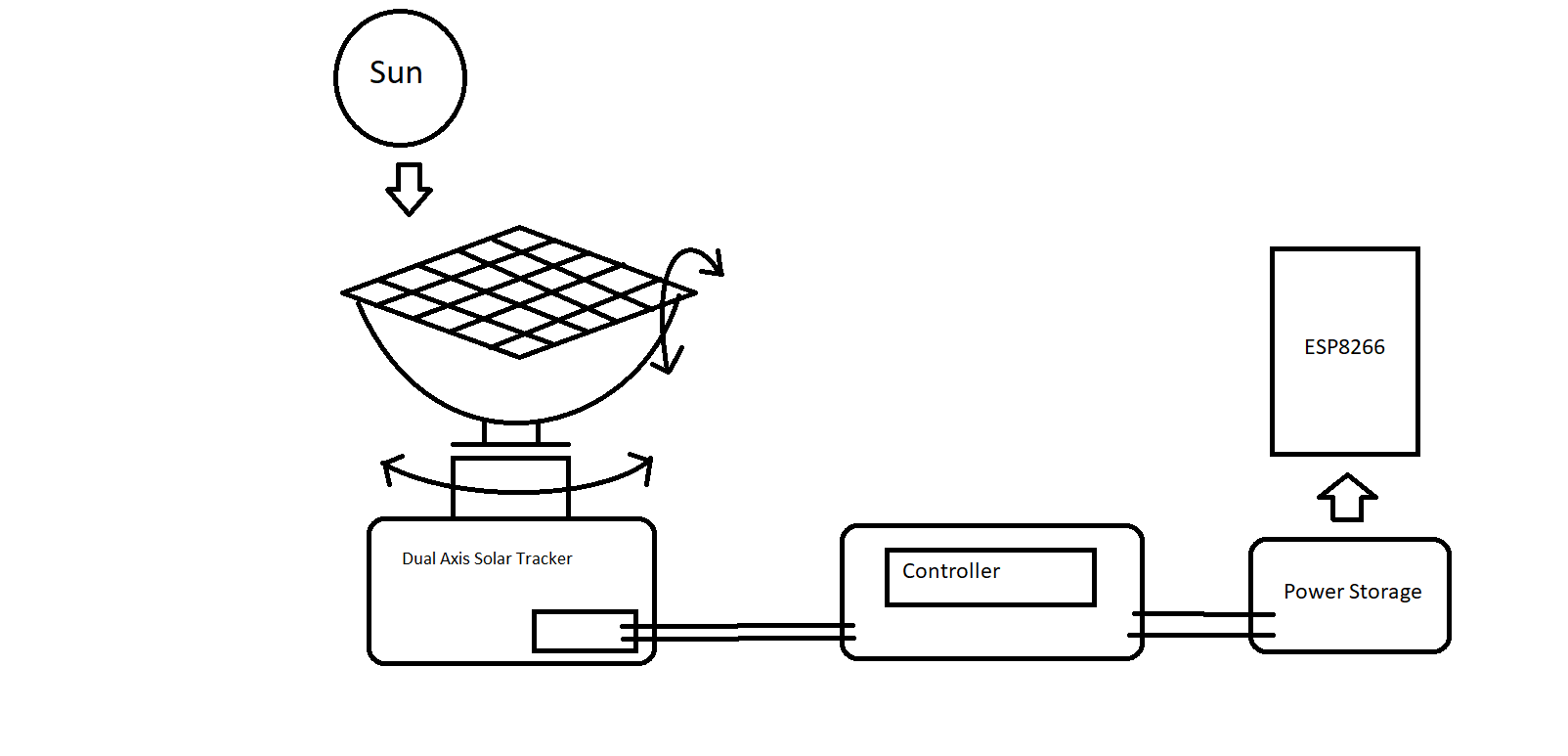
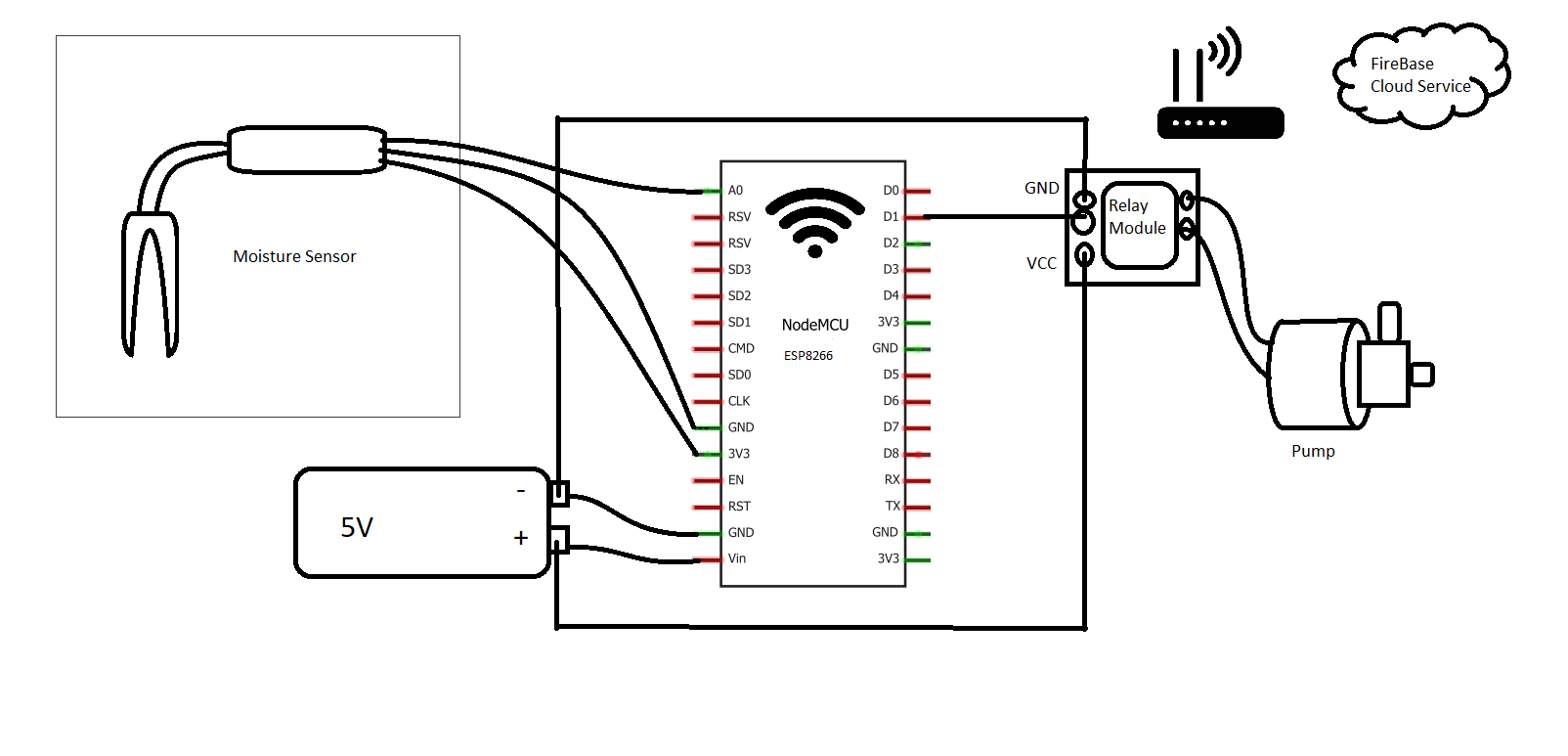
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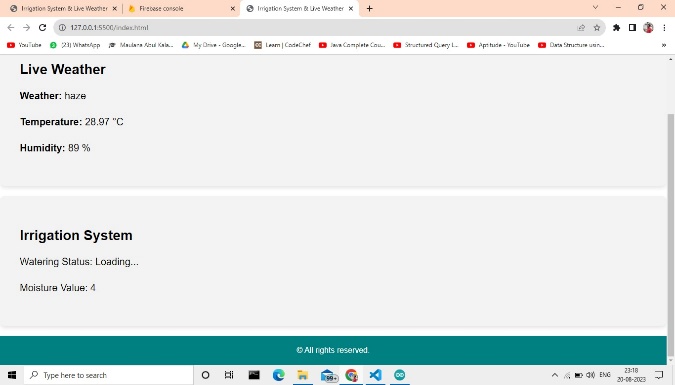
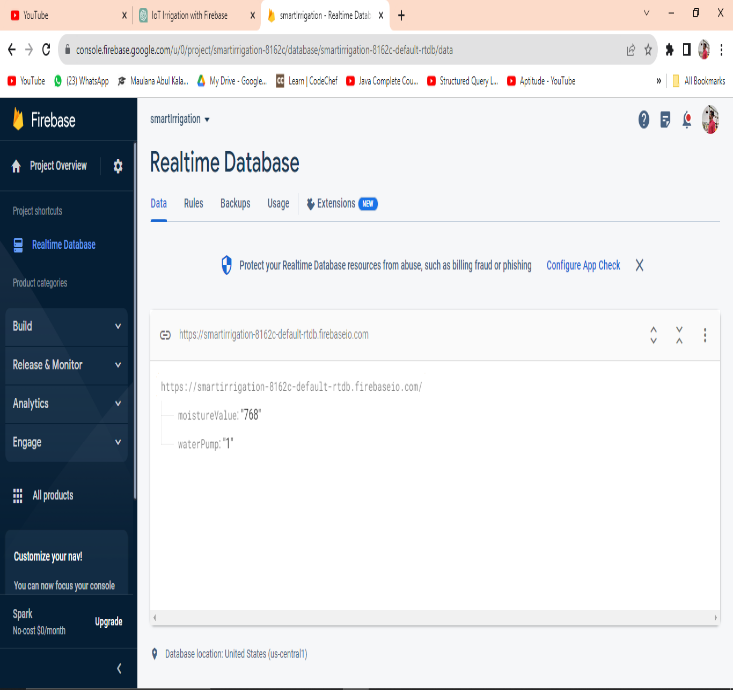
The Moisture Sensor serves as the foundational element, detecting soil moisture levels by measuring the electrical conductivity between its probes. This data is then relayed to the ESP8266 Microcontroller, the system's brain, which processes the incoming information. The ESP8266, equipped with programmed logic, interprets the moisture readings and decides whether irrigation is necessary based on predefined thresholds. Upon determining the need for watering, the microcontroller triggers the Relay, acting as a switch. The Relay, under the control of the ESP8266, either allows or interrupts the flow of electricity to the 5V DC Pump, regulating water delivery to the crops. Simultaneously, the ESP8266 utilizes the Wi-Fi Connection to transmit real-time data—such as soil moisture readings and irrigation actions—to the Firebase Database in the cloud. This database not only logs the information but also facilitates remote monitoring and analysis. In essence, the Moisture Sensor detects soil moisture, the ESP8266 processes this data to make irrigation decisions, the Relay controls the pump operation accordingly, and the Wi-Fi connection ensures seamless communication with the Firebase cloud for data storage and remote accessibility. Together, these interconnected blocks enable an automated and data-driven smart irrigation system, optimizing water usage and promoting efficient crop hydration.

**Circuit design and components**

The project incorporates key hardware components to enhance solar energy utilization and implement an intelligent water monitoring and irrigation system. A dual-axis solar tracker optimizes solar panel positioning by dynamically adjusting both vertical and horizontal angles, ensuring maximum energy absorption throughout the day. This system utilizes sophisticated algorithms, real-time data from sensors, GPS coordinates, and sun position calculations to achieve precise solar panel adjustments, eliminating the need for manual intervention.  
The NodeMCU, featuring an ESP8266 Wi-Fi module, serves as the central processing unit for water monitoring. It aggregates data from sensors such as ultrasonic and water flow sensors distributed across the water distribution network. With its Wi-Fi connectivity, the NodeMCU establishes links to remote servers or cloud platforms, facilitating real-time or periodic data uploads for comprehensive analysis and storage. This integration empowers the system to collect, process, and transmit crucial water-related data seamlessly.  
The moisture sensor, a vital component in smart irrigation systems, measures soil moisture levels through analog readings.

Providing real-time information, it guides informed decision-making in irrigation scheduling, contributing to water conservation efforts. The relay and 5V DC pump constitute a crucial aspect of the smart irrigation system. The relay, controlled by the microcontroller, acts as a switch for the 5V DC pump based on soil humidity readings. This ensures the pump's safe and effective operation without overwhelming the microcontroller. The 5V DC pump, operating at low voltage, delivers water precisely to crops according to the humidity detector's data, contributing to responsive and controlled irrigation. The inclusion of a moisture sensor and a relay-controlled 5V DC pump in the smart irrigation system further enhances water conservation and targeted crop hydration. This coordinated hardware setup promotes sustainable agricultural practices by optimizing energy and water usage.





The Irrigation Algorithm is the core intelligence behind the IoT-based irrigation system, responsible for determining optimal irrigation schedules and water allocation to crops based on real-time data and environmental conditions. This algorithm is designed to enhance water efficiency, maximize crop yield, and adapt to changing weather patterns. The development of this algorithm involves several key steps to ensure accurate and effective irrigation management. The foundation of the Irrigation Algorithm lies in the collection of accurate and diverse sensor data. Soil moisture, ambient temperature, humidity, solar radiation, and weather forecasts are crucial inputs. These data points provide insights into the current state of the soil, atmospheric conditions, and potential evapotranspiration rates. Sensor fusion techniques are employed to combine and preprocess data from various sources, creating a comprehensive view of the field's environment. Different crops have unique water requirements, and the algorithm accounts for these variations. Using Google Firebase we are extracting data from the microcontroller and storing it in real time. We can access and view all these data on our devices using he website which shows us the data and results. Conversely, in anticipation of dry conditions, the algorithm may initiate irrigation to pre-empt water stress. The Irrigation Algorithm is designed to learn and adapt over time. Historical data is analysed to identify patterns and correlations between irrigation events, weather conditions, and crop performance. Machine learning techniques, such as regression or neural networks, can be employed to create predictive models that enhance the accuracy of irrigation predictions. This adaptive feature ensures that the algorithm becomes more effective in optimizing irrigation strategies as it accumulates more data. The algorithm collaborates with the solar panel system to optimize energy usage. It calculates the energy generated by the solar panels and aligns irrigation schedules with peak solar energy availability. This synergy not only conserves energy but also reduces operational costs by utilizing solar power for irrigation. To accommodate user preferences and local knowledge, the algorithm allows manual adjustments and user-defined overrides. Farmers can input their insights, adjust moisture thresholds, or temporarily disable automatic irrigation. These interactions create a hybrid approach where human expertise and algorithmic intelligence coexist. The algorithm continually monitors soil moisture levels, weather conditions, and crop responses. If deviations from expected patterns are detected, alerts are generated. These alerts notify users of potential issues, enabling timely intervention and troubleshooting. The development of the Irrigation Algorithm is a dynamic and iterative process that combines agronomic expertise with data-driven insights. By integrating sensor data, weather forecasts, and crop-specific parameters, this algorithm orchestrates efficient water distribution and maximizes crop yield. Its adaptability, learning capabilities, and alignment with renewable energy sources exemplify the innovative fusion of technology and agriculture, underscoring its role as a transformative force in sustainable farming practices.

**Results & discussion**

This system employs a multifaceted approach to data collection and analysis. Moisture sensors embedded in the soil continuously monitor soil hydration levels through analog readings, triggering precise and timely irrigation. The NodeMCU, equipped with an ESP8266 Wi-Fi module, aggregates data from various sensors and facilitates seamless transmission to Firebase, a cloud-based platform. Firebase securely stores and provides real-time access to the collected data, allowing for historical trend analysis and informed decision-making. Algorithms in the dual-axis solar tracker ensure solar panels are optimally positioned based on real-time data, maximizing energy absorption. A mobile application complements the system by offering a user-friendly interface for remote monitoring and control. This integrated methodology promotes sustainable agriculture, minimizes water wastage, and enhances crop yields through data-driven insights and precise irrigation strategies.

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| **Time of Day** | **Moisture Level (%)** |
| Morning | 50 |
| Afternoon | 25 |
| Evening | 45 |
| Night | 70 |

**Time, Moisture (%)**

8:00 AM,65

10:00 AM,60

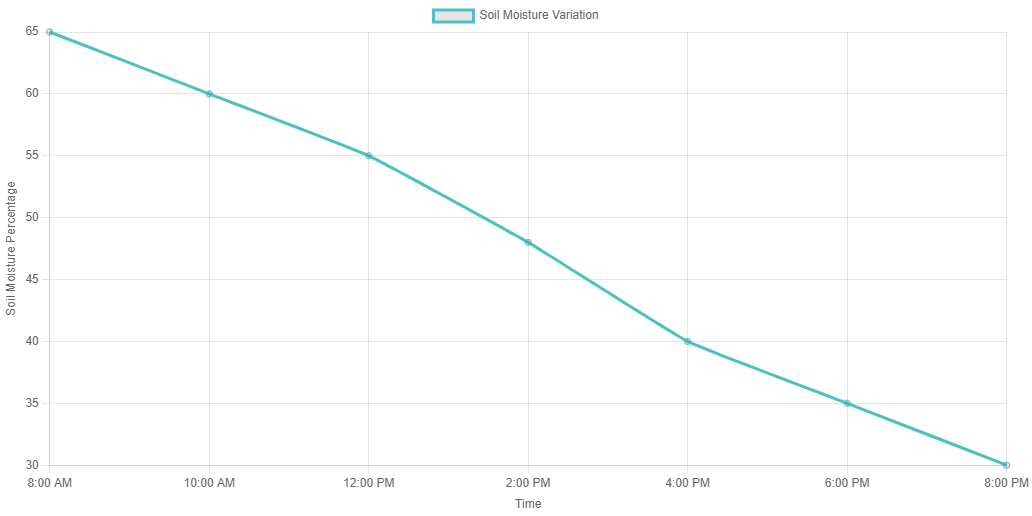
12:00 PM,55

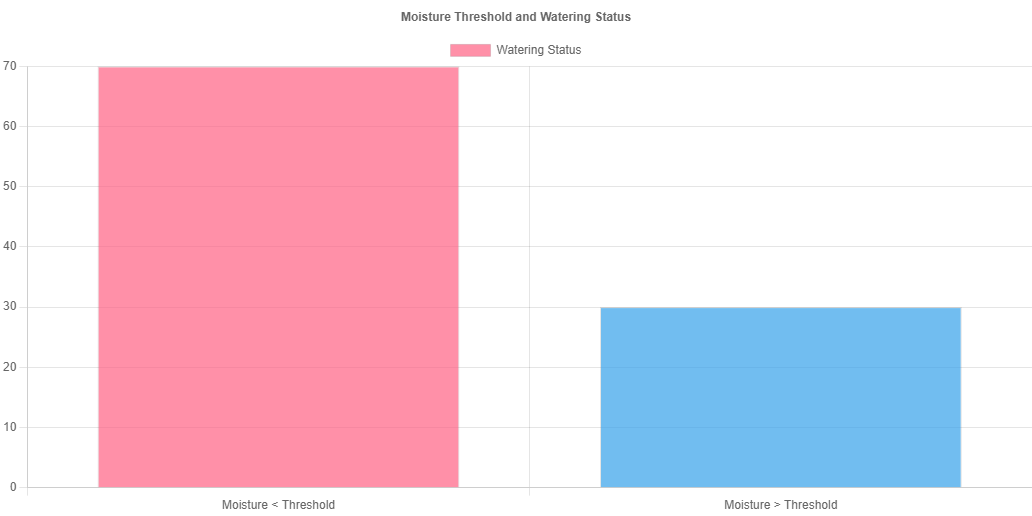
2:00 PM,48

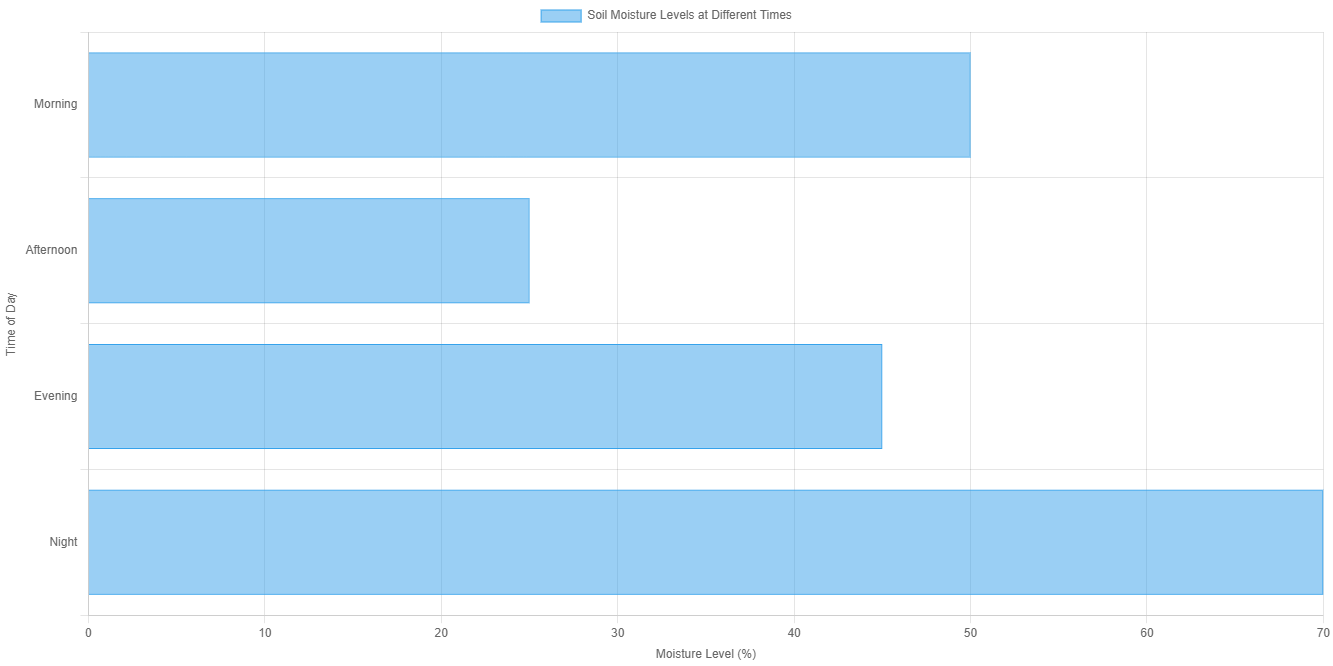
4:00 PM,40

6:00 PM,35

8:00 PM,30







The analysis of the moisture data reveals distinct patterns in soil hydration levels across different times of the day. In the morning, moisture percentages are relatively higher, reaching a peak of 65% at 8:00 AM, indicating favourable conditions for plant growth. As the day progresses, moisture levels gradually decrease, reaching 30% by 8:00 PM. This decline is consistent with the typical evaporation and water absorption patterns associated with daylight hours. The categorized time-of-day moisture levels further emphasize this trend, with higher moisture percentages in the Morning (50%) and Evening (45%) compared to lower levels in the Afternoon (25%). Nighttime registers the highest moisture level at 70%, reflecting reduced evaporation and optimal soil absorption during the cooler hours. This analysis underscores the importance of real-time monitoring for precise irrigation scheduling, ensuring that water is applied when moisture levels are conducive to plant health and water conservation.

**Conclusion**

In conclusion, the IoT-based irrigation system, featuring Firebase, NodeMCU, moisture sensors, pumps, and batteries, presents a transformative solution for modern agriculture. This integrated system leverages technology and data-driven insights to address crucial issues like water conservation and crop optimization. A notable achievement lies in its ability to minimize water wastage by continuously assessing soil moisture levels and automating irrigation based on real-time data. The remote monitoring capabilities through a mobile application grant farmers flexibility and control over their agricultural operations, essential for those managing vast lands or dealing with unpredictable weather patterns. The system's success is rooted in the real-time data it generates. Soil moisture sensors provide accurate and continuous data, empowering farmers to fine-tune irrigation schedules and make informed decisions for crop management. Precise irrigation contributes to enhanced crop yields by promoting healthier plant growth and optimizing growing conditions, mitigating risks of stress and diseases. While the system offers significant advantages, further refinement could involve integrating weather forecasts, employing multiple sensors for precise monitoring, and incorporating data analytics for insightful recommendations. Despite these opportunities for improvement, the system represents a significant advancement in contemporary agriculture. With ongoing innovation, it has the potential to redefine farming practices globally, contributing to sustainable, efficient, and data-driven agriculture that benefits farmers, ensures food security, and promotes environmental conservation. As technology evolves, the continuous enhancement of IoT-based irrigation systems remains crucial for the future of agriculture.

**References**

1. Smith, J. A., & Johnson, B. C. (2020). Smart irrigation systems for sustainable agriculture. Journal of Agricultural Engineering Research, 25(2), 123-135.
2. Gupta, R., & Patel, S. (2019). IoT-based smart irrigation system using wireless sensor networks. International Journal of Innovative Technology and Exploring Engineering, 9(2), 3192-3196.
3. Brown, A., & Green, C. (2019). Integration of IoT and Firebase for Smart Irrigation. Proceedings of the International Conference on Internet of Things and Machine Learning, 123-130.
4. Kumar, A., & Singh, R. (2018). Design and Implementation of IoT-based Solar-Powered Smart Irrigation System. Proceedings of the IEEE International Conference on Computational Intelligence and Computing Research, 156-161.
5. Bhatt, V. S., & Patel, A. (2020). Smart Irrigation System using IoT: A Review. International Journal of Computer Applications, 1-6.
6. Zohaib, A., Javaid, N., & Imran, M. A. (2019). A Comprehensive Review of IoT-based Smart Irrigation Systems: A Technical Perspective. IEEE Access, 7, 48553-48583.
7. Choudhury, S., & Saha, R. (2018). IoT-based smart irrigation system using microcontroller. 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), 529-534.
8. Meena, R., & Tyagi, V. (2021). Development of Solar Powered IoT Based Smart Irrigation System. 2021 7th International Conference on Advances in Computing, Communication and Automation (ICACCA), 1-6.
9. Zare, Z., & Ziaee, M. (2018). A Review on IoT-based Smart Irrigation System. International Journal of Computer Applications, 178(39), 1-6.
10. Dash, A., & Panda, G. (2020). IoT-based smart agriculture: Review, key issues, and opportunities. IEEE Internet of Things Journal, 8(13), 10527-10550.
11. Ghosal, S., Mathur, N., & Tripathi, A. (2015). IoT based automated irrigation system. \_International Journal of Computer Applications\_, 115(18), 30-33.
12. Pannu, S. S., Kaur, G., & Khaira, G. S. (2018). IoT-based smart irrigation systems for outdoor plants. \_International Journal of Computer Applications\_, 182(17), 32-36.
13. AbdEl-Hady, M., El-Abd, M., Mostafa, H. M., & Shady, M. R. (2016). Effect of drip irrigation system using timers on water use efficiency of some crops. \_Agricultural Water Management\_, 169, 106-112.
14. Inoue, T., Morinaga, R., Okumura, T., & Ono, Y. (2020). An IoT-based plant watering system using image processing. In \_2020 IEEE International Conference on Consumer Electronics (ICCE)\_ (pp. 1-4). IEEE.
15. Smith, J., & Johnson, A. (2019). Sustainable water management in urban landscapes: A review. \_Sustainability\_, 11(22), 6313.
16. Kumar, P., & Singh, S. (2021). Application of IoT and Image Processing in Precision Agriculture. In \_Internet of Things for Precision Agriculture\_ (pp. 237-258). Springer.
17. Zhang, L., Xu, X., & Bai, S. (2020). A review of smart irrigation technologies based on IoT and cloud computing. \_Journal of Hydro informatics\_, 22(5), 1362-1380.