**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**

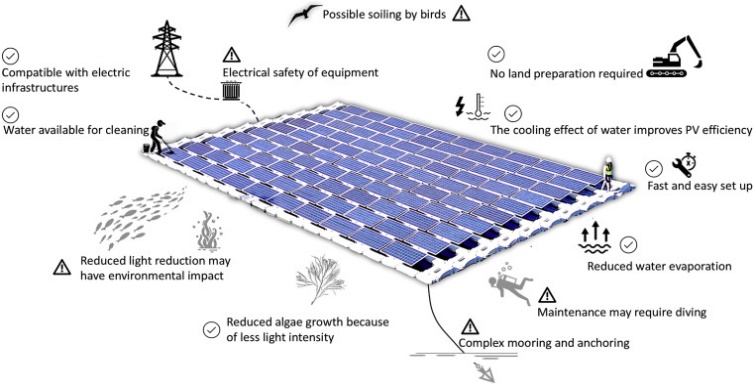
The intersection of rapid urbanization and the imperative need for sustainable agricultural practices has led to the development of innovative irrigation solutions. One of the key technologies driving this transformation is the Internet of Things (IoT), which has revolutionized traditional agricultural practices through real-time data perception and precise irrigation management, thereby minimizing water wastage and promoting efficient water conservation in the agricultural sector (Smith & Johnson, 2020). With the integration of wireless sensor networks, IoT-based smart irrigation systems have shown their capability to provide crucial real-time data on soil moisture levels and environmental conditions, facilitating informed decision-making for optimized irrigation strategies (Gupta & Patel, 2019). Additionally, the incorporation of IoT with Firebase has streamlined data management and communication, enhancing the overall efficiency of smart irrigation systems (Brown & Green, 2019). Moreover, the convergence of IoT technology with solar-powered irrigation systems has displayed the potential to reduce dependence on traditional energy sources, contributing significantly to sustainable agricultural practices and environmental conservation efforts (Kumar & Singh, 2018). Extensive research has underscored the crucial role played by IoT in enhancing water-use efficiency and promoting sustainable agricultural development (Bhatt & Patel, 2020; Zohaib, Javaid, & Imran, 2019). The successful implementation of IoT-driven irrigation systems has emphasized the critical role of microcontrollers and innovative technologies in enabling precise monitoring and control of irrigation processes, ensuring optimal water usage and promoting agricultural sustainability (Choudhury & Saha, 2018; Inoue et al., 2020). Notably, the deployment of automated irrigation systems has significantly improved water use efficiency in various crop cultivation practices, highlighting the transformative potential of IoT in revolutionizing contemporary agricultural methodologies (AbdEl-Hady et al., 2016). Furthermore, the fusion of IoT and image-processing techniques has revolutionized the landscape of precision agriculture, providing vital insights into plant health and growth dynamics, crucial for the development of tailored and effective irrigation strategies (Kumar & Singh, 2021). The seamless integration of IoT technology and cloud computing in smart irrigation systems has spurred significant advancements in water management practices, emphasizing the critical role of data-driven decision-making in achieving sustainable agricultural development and resource optimization (Zhang, Xu, & Bai, 2020). In light of these integrated approaches, it is evident that advanced technologies play a pivotal role in addressing contemporary challenges in agriculture, especially in the context of water resource management and sustainable irrigation practices. Amidst the ongoing challenges of water scarcity and environmental degradation, the implementation of IoT-based smart irrigation systems has garnered attention as a promising solution for optimizing water usage and enhancing agricultural productivity (Dash & Panda, 2020). These systems leverage sophisticated sensor technologies to monitor and manage key environmental parameters, such as soil moisture levels, weather conditions, and crop health, enabling farmers to make informed decisions and adjust irrigation practices accordingly (Ghosal, Mathur, & Tripathi, 2015). Such precision in irrigation management has been instrumental in achieving sustainable water use and fostering efficient agricultural practices, particularly in regions prone to water scarcity and climatic variability (Pannu, Kaur, & Khaira, 2018). Furthermore, the advent of IoT-driven plant watering systems utilizing image processing has brought about significant advancements in the accurate assessment of plant hydration needs and overall crop health (Inoue et al., 2020). By harnessing image processing algorithms, these systems can provide comprehensive insights into the growth dynamics and physiological well-being of plants, thereby facilitating the implementation of targeted and adaptive irrigation strategies tailored to specific crop requirements (Smith & Johnson, 2019). The seamless integration of IoT technologies with image processing tools has the potential to revolutionize the field of precision agriculture, enabling farmers to optimize water usage, reduce environmental impacts, and ensure sustainable agricultural production (Kumar & Singh, 2021). In this context, it is evident that the integration of IoT in irrigation systems represents a critical paradigm shift in sustainable agricultural practices, offering significant promise for enhancing water management efficiency and agricultural sustainability in the face of growing environmental challenges (Zhang, Xu, & Bai, 2020).

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.

**1. Dual-axis solar tracker**

Solar energy has surfaced as a possible source of renewable energy over the once two to three decades. This solar energy is converted into electrical energy by using solar panels according to the principle of photovoltaic effect. Out of colourful renewable energy sources solar energy is extensively used. Because it's simple and it's easy to use in ménage too. Solar Trackers is a device used for the gyration of solar panels according to the sun’s shafts. To use this renewable solar energy solar trackers are employed.



**Fig 1: Structure of solar tracker**

For stationary solar panels, there's no movement in the panel. But the position of the sun changes during rising and setting(the sun rises in the east and sets in the west). Due to this reason, a single-axis solar shamus is developed for the gyration of solar panels in east and west directions. But due to the gyration and revolution of the earth, we can not get an equal quantum of sunrays throughout time. So we espoused binary axis solar shamus to use the solar energy effectively and efficiently by rotating the panel in both vertical and perpendicular directions. The main idea of the binary axis solar shamus is to increase the effectiveness of the solar panel by 30- 45 when compared to the static and single-axis solar shamus. The literature check easily shows the different styles of solar shadowing for the maximum application of solar power. Solar panels consist of multiple solar cells, each comprising semiconductor materials. When sunlight strikes these cells, photons release electrons, generating an electric current. This direct current (DC) is then converted into alternating current (AC) through an inverter, making it suitable for powering electronic components within the irrigation system. Efficient solar panel placement involves selecting optimal locations that receive maximum sunlight exposure throughout the day. Factors such as shading, geographical orientation, and nearby structures need to be considered to ensure consistent sunlight access. Additionally, the elevation angle and azimuth angle are crucial parameters for maximizing energy capture. A significant advancement in solar panel optimization is the implementation of dual-axis solar tracking mechanisms. Traditional fixed solar panels are positioned at a fixed angle relative to the ground. However, dual-axis tracking systems automatically adjust both the elevation (tilt angle) and azimuth (orientation angle) of the panels to directly face the sun as it moves across the sky. This dynamic adjustment significantly enhances energy collection by maintaining an optimal angle of incidence between the sunlight and the solar panel surface. The dual-axis tracking system ensures that solar panels are perpendicular to the sun's rays at all times, maximizing energy absorption. In the morning, the panels face east to capture early sunlight, while in the afternoon, they follow the sun westward. This constant alignment yields higher energy output compared to fixed panels, where the angle remains constant and suboptimal throughout the day. Sophisticated algorithms play a pivotal role in calculating the precise angles for solar panel adjustments. These algorithms incorporate real-time data from sensors, GPS coordinates, and sun position calculations based on the time of day and geographic location. The use of computational methods ensures accurate adjustments and eliminates the need for manual intervention.

Moreover, reduced reliance on grid electricity contributes to long-term cost savings for the farmer, making the system economically viable. Solar panel installation not only benefits the irrigation system but also aligns with sustainable agriculture practices

The solar panel adjustment mechanism is automated and integrated into the irrigation system's control unit. Microcontrollers receive data from sensors that detect sun positions, and based on predefined algorithms, the actuators control the angles of the panels. This automation ensures seamless and accurate adjustments, eliminating the need for constant manual monitoring. The implementation of dual-axis solar tracking leads to higher energy efficiency, resulting in increased energy production compared to fixed panels. This surplus energy can be stored in batteries or used to power additional features of the irrigation system.

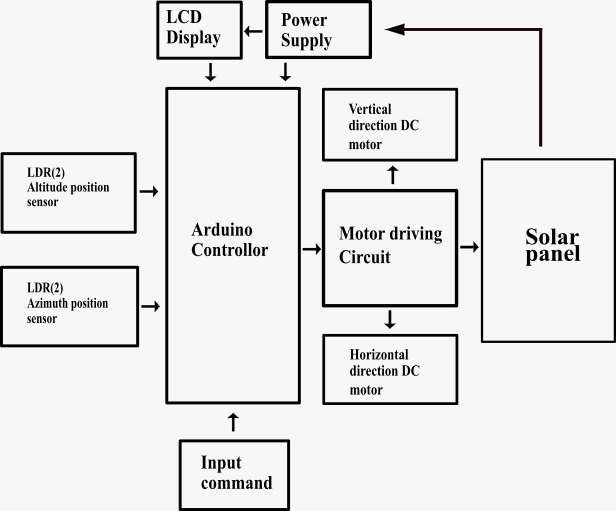


Fig2: block diagram of dual axis solar tracker

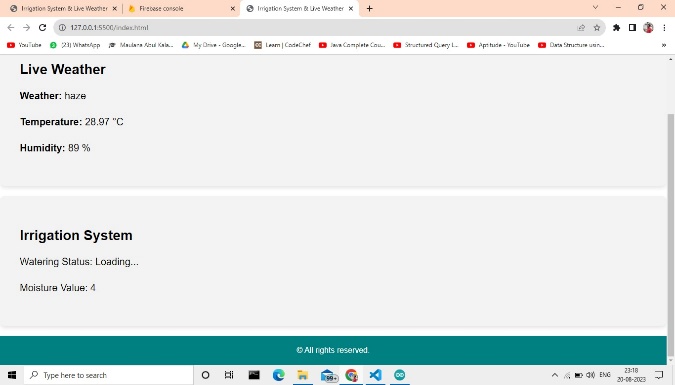
. By harnessing clean and renewable solar energy, the system reduces carbon emissions and minimizes the environmental footprint associated with traditional energy sources. Solar panel installation and dual-axis angle adjustment represent a transformative approach to powering IoT-enabled smart irrigation systems. By seamlessly integrating renewable energy sources and advanced tracking mechanisms, the system achieves unparalleled energy efficiency and environmental sustainability. This integration paves the way for a future where agricultural operations can harness the power of the sun to optimize water management, enhance crop yields, and contribute to a greener and more resilient agricultural landscape.

**2. Nodemcu and Moisture Sensor**

The NodeMCU serves as the central processing unit of the IoT-based irrigation system. This open-source platform, built upon the ESP8266 Wi-Fi module, is responsible for orchestrating the entire system's operations. Its primary functions include collecting data from the moisture sensor, establishing communication with the Firebase cloud, and controlling the irrigation pump. To achieve these tasks, NodeMCU is programmed with firmware that allows it to read data from the moisture sensor, connect to a Wi-Fi network, and interact with Firebase through APIs. Additionally, NodeMCU manages the logical operations that govern when and how the irrigation pump is activated based on the real-time moisture data it receives. The moisture sensor, on the other hand, plays a pivotal role in gathering essential information about soil conditions. Installed within the soil, this sensor provides constant and precise data on soil moisture levels. Its primary function is to measure the moisture content in the soil, which is vital for determining when irrigation is required. The sensor employs a basic yet effective principle: it has two electrodes that measure the resistance between them. This resistance is inversely related to the moisture content in the soil. Dry soil exhibits high resistance, while wet soil has low resistance. By measuring this resistance, the moisture sensor can calculate and transmit moisture level values that NodeMCU can then utilize for decision-making. The irrigation pump, its primary function is to transport water from a designated water source, such as a reservoir, to the irrigation system where it can be efficiently distributed to the crops.

When activated, the pump's electric motor propels water through a network of pipes, ensuring that the plants receive the necessary hydration. NodeMCU controls the irrigation pump through a relay or similar switching mechanism. When the system determines that soil moisture has fallen below a predefined threshold, it sends a signal to the relay, which, in turn, activates the pump. This synchronized operation ensures that water is delivered precisely when needed. As for the power source, the battery is a critical component in an IoT-based irrigation system. Its primary function is to provide consistent and reliable power to the NodeMCU and other electronic components, enabling the system to operate continuously. In remote agricultural areas or locations lacking a dependable power supply, batteries are indispensable. These batteries store electrical energy and release it as needed to power NodeMCU and other system components. The choice of battery capacity and type depends on the system's power consumption and the desired runtime. Additionally, in sustainable implementations, such as in solar-powered systems, batteries are charged using energy harnessed from solar panels, making the irrigation system environmentally friendly and self-sustaining. Lastly, Firebase, a cloud-based platform developed by Google, plays a pivotal role in data management and communication within the IoT-based irrigation system. Its primary function is to store, organize, and facilitate data exchange between NodeMCU and the mobile application, ensuring seamless remote monitoring and control. NodeMCU continuously sends soil moisture data to Firebase's real-time database. Firebase, in addition to data storage, provides authentication mechanisms to ensure secure access to the system. The mobile application, in turn, connects to Firebase to retrieve the latest data and send control commands back to NodeMCU. Firebase's real-time capabilities ensure that data remains synchronized, enabling users to monitor and manage the irrigation system in near real-time. This cloud-based infrastructure enhances the efficiency and accessibility of the entire irrigation system. . The sensors were strategically placed within the agricultural field to capture accurate data. Wiring and connections were established to ensure seamless communication between the sensors and the central control unit. The heart of the project lies in its software development. The central control unit was programmed to collect data from the IoT sensors at regular intervals. This data was then processed to calculate real-time soil moisture levels and weather conditions. The integration with Firebase facilitated the storage and transmission of data to the cloud-based platform. Web-based interfaces were created to enable remote monitoring and control of the irrigation system, giving farmers access to critical information. Collected data was subjected to comprehensive analysis to derive actionable insights. Statistical tools were employed to correlate soil moisture levels, weather conditions, and crop health. Data trends were identified to determine optimal irrigation intervals and amounts. Using this information, the project aimed to create an algorithm that could autonomously control the irrigation system based on real-time conditions. The methodology involved rigorous testing and calibration to ensure the accuracy and reliability of the system. Different scenarios were simulated to evaluate the system's responsiveness to varying conditions. Calibration of IoT sensors and solar panel angles was conducted to fine-tune the accuracy of data readings and energy harvesting. Upon successful testing, the system was implemented in a real agricultural field. Continuous monitoring was conducted to assess the system's performance in real-world conditions. Data collected from the field provided valuable insights into the system's effectiveness in optimizing water usage and improving crop yields. The project also addressed scalability, aiming to provide a solution that could be adapted to various farm sizes and crop types. Furthermore, the project's methodology acknowledged the potential for future enhancements, such as integration with advanced technologies like artificial intelligence for predictive analytics and machine learning for optimized irrigation decision-making. Recognizing the potential connectivity challenges, the project methodology included strategies to mitigate such issues. The placement of IoT sensors was carefully considered to ensure optimal signal reception. Additionally, signal amplifiers and range extenders were explored to enhance communication reliability. Continuous monitoring of connectivity was conducted during field implementation to identify and address any dropouts promptly. To ensure the security of transmitted data, the methodology incorporated robust encryption protocols. Data encryption mechanisms were implemented during data transmission from the IoT sensors to the central control unit and further to the Firebase platform. This approach aimed to safeguard sensitive agricultural information and build trust among farmers in adopting IoT technology. An essential aspect of the project was educating farmers about the system's functionalities and benefits. Workshops, training sessions, and instructional materials were developed to familiarize farmers with the remote monitoring and control features. This step aimed to bridge the gap between technological advancements and farmers' understanding, encouraging widespread adoption. Following field implementation, continuous monitoring and data collection were conducted over an extended period. The project methodology emphasized iterative improvements based on real-world observations and feedback from farmers. This iterative process aimed to enhance system performance, address unforeseen challenges, and refine algorithms for irrigation management. The methodology highlighted the importance of data-driven decision-making for optimizing irrigation practices. Collected data was analysed using statistical methods and algorithms to identify patterns and correlations. This analysis informed irrigation scheduling decisions based on actual soil moisture levels, weather conditions, and crop health, moving away from conventional fixed schedules. The integration of dual-axis solar panels brought forth a unique aspect of energy optimization. The project methodology included techniques for maximizing solar energy capture by adjusting panel angles dynamically based on sunlight orientation. Solar energy data was collected and analysed to fine-tune panel positions for optimal energy harvesting. Throughout the project, collaboration between experts from various fields was emphasized. Agronomists, IoT specialists, software developers, and engineers worked together to ensure a comprehensive approach that aligned with agricultural, technological, and environmental considerations. To assess the project's overall environmental impact, a comprehensive evaluation of energy savings, water conservation, and carbon emissions reduction was conducted. Quantitative analysis was performed to determine the project's contribution to mitigating the ecological footprint of agricultural practices. This step aimed to provide a holistic view of the project's sustainability and align with global efforts for environmental conservation. The project methodology included the design of a user-friendly interface for farmers to interact with the system. The graphical user interface (GUI) was developed to display real-time data, irrigation schedules, and system status in an intuitive manner. Usability testing and user feedback were incorporated to refine the interface for enhanced user experience. The algorithm responsible for autonomous irrigation decisions was rigorously validated. Performance metrics, such as water savings, crop yield improvements, and energy efficiency gains, were established to quantify the algorithm's effectiveness.

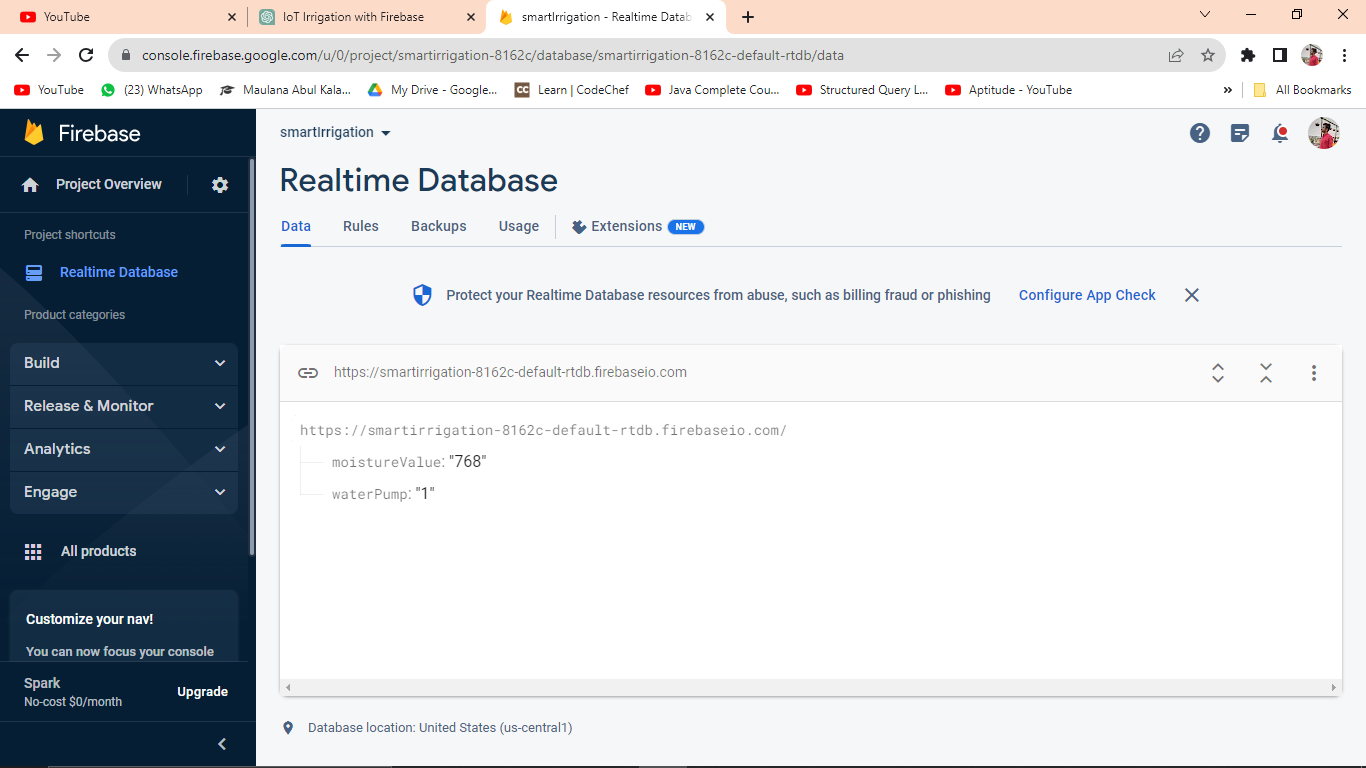
**3.User interface**



**Fig3: Our website**

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.

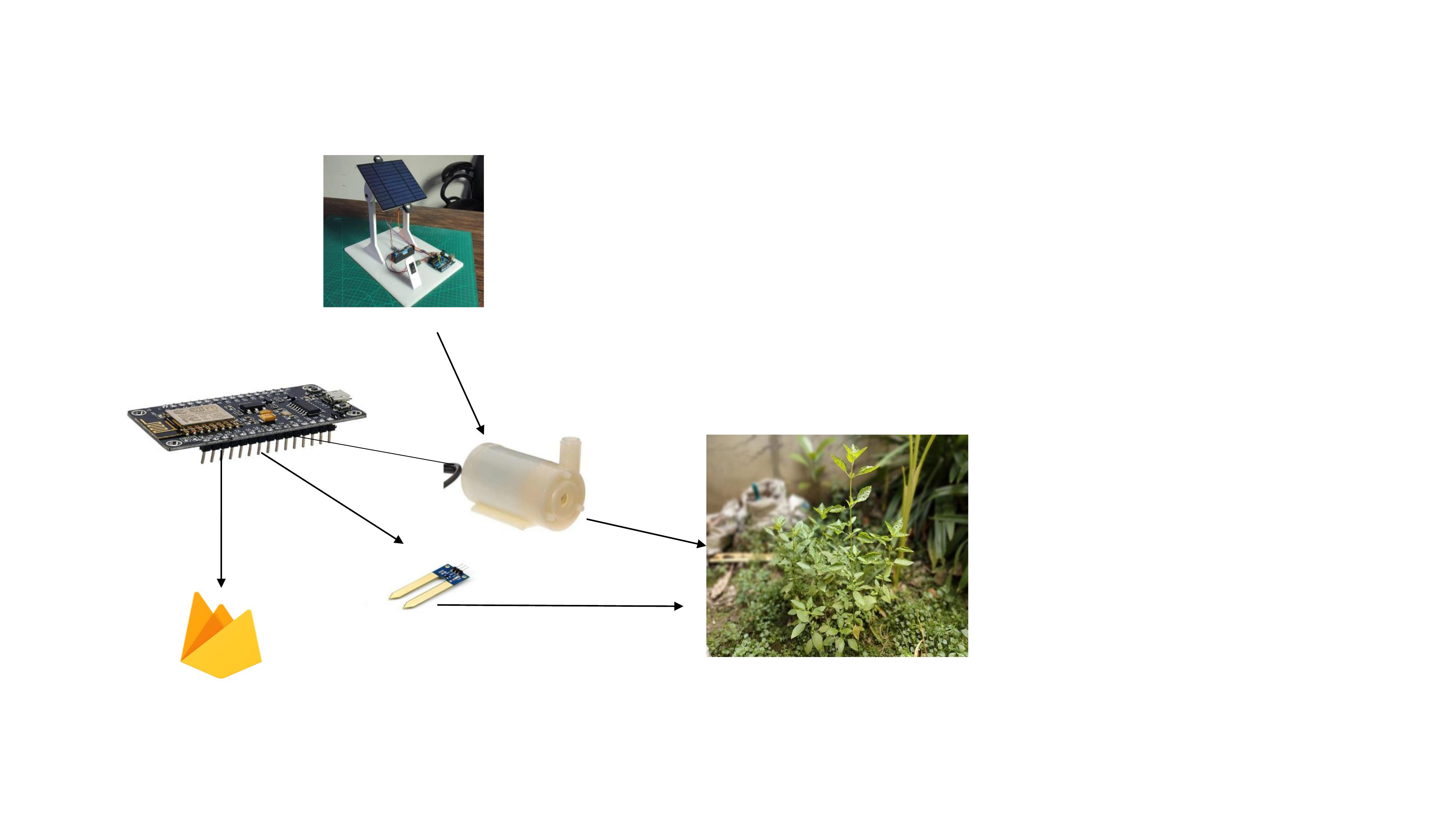


**Fig4: Database**

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**

In the intricate and innovative IoT-based irrigation system, the journey begins with the solar panel, a meticulously positioned and technologically advanced marvel designed to capture the abundant energy of sunlight. Comprised of photovoltaic cells, these panels harness solar radiation, diligently converting it into a vital electrical energy source, primarily in the form of direct current (DC). The meticulous management of this solar energy is crucial; hence, it flows first to a charge controller. The charge controller, a veritable guardian of the system's efficiency and longevity, steps into the spotlight. Its responsibility is multifaceted: regulating the voltage and current generated by the solar panel, thus facilitating the efficient charging of a dedicated battery while safeguarding it from overcharging, a potentially damaging condition, and deep discharge, which could significantly curtail its lifespan.

unswerving and uninterrupted system operation.  


**fig5 : Block diagram**  
In parallel, strategically positioned soil moisture sensors, an embodiment of precision and sophistication, burrow into the agricultural terrain. These sensors embark on a continuous journey, a mission to monitor and decipher the mysteries of the soil's moisture content. Their method, seemingly simple yet profoundly effective, centers on measuring the electrical resistance between their electrodes. Dry soil, characterized by higher resistance, stands in stark contrast to wet soil, offering lower resistance values. These fluctuations in resistance, these subtle changes, are painstakingly transmuted into actionable moisture level data, which is then transmitted with unwavering commitment to the NodeMCU at meticulously defined intervals. This data collection process ensures a continuous and comprehensive grasp of soil hydration levels across the expanse of the agricultural domain.  
  
The NodeMCU, a digital maestro orchestrating the entire system, now takes its place in the spotlight. It steps into action, a vigilant guardian of the soil's moisture equilibrium. Continuously collecting data from the moisture sensors, it embarks on a real-time journey of analysis and interpretation, a journey that involves intricate algorithms and complex decision-making processes. The NodeMCU, armed with this sophisticated algorithmic arsenal, ventures to compare the current moisture levels with predefined thresholds, thresholds that encapsulate the optimal hydration conditions for the crops in question. And when it senses, with unparalleled precision, that the soil's moisture has dipped below the sacred threshold, it triggers the irrigation system into action, a symphony of precise water delivery.  
  
But the irrigation pump, a vital conductor in this symphony, does not awaken on its own accord. It awaits the NodeMCU's command, typically mediated by a relay module, a digital switchboard. The relay module, a bridge between the digital and the physical, becomes the NodeMCU's loyal servant. It obeys the NodeMCU's commands without hesitation, allowing the irrigation pump to surge to life, to deliver water with unerring accuracy, in exact quantities and at precise moments, a choreography designed to minimize waste and optimize the crops' hydration.  
  
And then, there's Firebase, the system's benevolent overseer of data. It plays a pivotal role, ensuring that data flows seamlessly and securely between the digital realm and the cloud. The NodeMCU establishes a secure and efficient connection with Firebase, a cloud-based database platform with boundless storage capacity and a thirst for real-time data. Firebase becomes the keeper of the data flame, faithfully accepting the NodeMCU's offerings, including soil moisture levels, irrigation system status (on or off), and the battery's state of charge.  
  
Firebase's role doesn't stop at data acceptance; it extends to data organization and accessibility. Within Firebase's digital confines, data is meticulously organized and stored in real-time, a digital sanctuary where information flows freely and is readily accessible for further analysis, remote monitoring, and control.

To offer users, particularly farmers, a window into this intricate ecosystem, a dedicated website or web application emerges. This digital portal is more than a mere interface; it's a gateway to empowerment and data-driven decision-making. Users, with the aid of secure logins, enter a world of real-time data representation. Soil moisture levels, irrigation system status, and historical moisture trends come to life in intuitive visuals and informative charts. But this digital realm isn't limited to data display alone. It extends an olive branch of remote control, allowing users to wield the power of decision over the irrigation pump's fate. With a few clicks, users can toggle the irrigation pump on or off, guided by real-time soil moisture data and their unique preferences, transforming remote control into an art form.  
  
As the system progresses, the battery emerges as a silent but formidable protagonist, ensuring that the show goes on. It is this unassuming power source that sustains continuous operation, ensuring that the NodeMCU and its digital companions never falter. However, this role isn't a solitary one; it relies on the solar panel's generosity. During daylight hours, when the solar panel showers the system with excess energy, a charge controller assumes the role of the wise conductor. It directs surplus energy with grace and precision, channelling it into the battery's waiting embrace. This careful energy management ensures a steady and unwavering power supply, even during the darkest moments of limited sunlight.

**Conclusion**

In conclusion, the IoT-based irrigation system incorporating Firebase, NodeMCU, moisture sensors, pumps, and batteries represents a transformative solution for modern agriculture. This system combines technology and data-driven insights to revolutionize irrigation practices, addressing critical issues such as water conservation, crop optimization, and remote monitoring. A standout achievement of this system is its capacity to minimize water wastage. By continually assessing soil moisture levels and automating irrigation based on real-time data, it mitigates excessive water usage. This not only aligns with sustainable farming practices but also addresses the global challenge of water scarcity, particularly in regions heavily reliant on irrigation. The remote control and monitoring capabilities offered by the mobile application are another remarkable aspect of this system. Farmers can oversee and manage their irrigation systems from anywhere, granting them unparalleled flexibility and control over their agricultural operations. This capability is especially beneficial for those managing extensive agricultural lands or dealing with unpredictable weather patterns. Central to the system's success is the real-time data it generates. Soil moisture sensors provide continuous and accurate data, which is transmitted to Firebase, securely stored, and made accessible for analysis and control. This real-time data empowers farmers to fine-tune irrigation schedules, track historical moisture trends, and make data-informed decisions for crop management. Enhanced crop yields are a direct result of the system's precise irrigation capabilities. By delivering water at the right time and in the right amounts, it promotes healthier plant growth and optimizes growing conditions. The ability to prevent both over-irrigation and under-irrigation reduces the risk of crop stress and diseases, ultimately leading to improved crop yields and quality. While this IoT-based irrigation system offers numerous advantages, there is scope for further refinement and expansion. Integration with weather forecasts could enhance decision-making by adjusting irrigation schedules based on anticipated rainfall. Employing multiple moisture sensors in different areas of the agricultural land would enable more precise monitoring and tailored irrigation strategies for specific crop needs. Additionally, incorporating data analytics could provide valuable insights and recommendations, aiding farmers in making even more informed choices for crop management. Efforts should also focus on optimizing NodeMCU's power consumption to extend battery life. Exploring sustainable energy solutions, such as larger battery capacities or solar panels, can ensure uninterrupted system operation. Furthermore, data security remains a paramount concern in future iterations. As agriculture processes become increasingly digitized and interconnected, safeguarding data and ensuring secure access to the system is vital to protect the interests of farmers and the integrity of the agricultural supply chain. In essence, the IoT-based irrigation system utilizing Firebase, NodeMCU, moisture sensors, pumps, and batteries represents a significant advancement in contemporary agriculture. It offers a practical and sustainable solution to the challenges of water management, crop cultivation, and remote agricultural monitoring. With continued innovation and refinement, this system holds the potential to redefine agricultural practices, contributing to sustainable, efficient, and data-driven farming practices worldwide. Its adoption not only benefits farmers but also plays a pivotal role in global food security and environmental conservation. As technology continues to evolve, the opportunities to enhance and expand the capabilities of IoT-based irrigation systems are boundless, making them an indispensable tool for 21st-century 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.