International Journal of Technology and Applied Science (IJTAS)
E-ISSN: 2230-9004 ● Website: www.ijtas.com ● Email: editor@ijtas.com

Smart Home Garden Irrigation System Using NodeMCU ESP8266 for Automated Plant Water Management

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1. Introduction

The increasing adoption of home gardening in urban and residential environments has created a need for efficient plant-care practices that minimize resource consumption while maintaining suitable growing conditions. Home gardens provide an accessible means of producing vegetables, fruits, herbs, and ornamental plants within limited residential spaces, but their productivity depends strongly on appropriate irrigation management. Water availability in the plant root zone directly influences physiological processes, nutrient transport, photosynthetic activity, and plant growth. Irrigation based only on fixed time intervals or manual observation does not account for variations in soil moisture, rainfall, temperature, humidity, and solar radiation. Such practices result in unnecessary water application during periods of adequate soil moisture and insufficient irrigation during dry conditions. Obaideen et al. (2022) reported that the integration of sensors, automation, and Internet of Things (IoT) technologies provides an effective framework for monitoring soil and environmental conditions and improving irrigation management. The requirement for intelligent irrigation has increased with growing pressure on freshwater resources and changing climatic conditions. Irrigation management requires information regarding the timing, quantity, and location of water application, and these parameters depend on the interaction between soil, plant, atmospheric conditions, and available water. Togneri et al. (2023) emphasized that water-need estimation represents a fundamental component of precision irrigation because accurate information about soil moisture and environmental conditions supports decisions regarding when and how much water should be supplied. The increasing availability of sensor-generated data through IoT platforms has further expanded the scope of real-time irrigation monitoring and data-driven control. Soil moisture represents one of the most important parameters for automated irrigation because it provides a direct indication of the water status of the plant-growing medium. Soil moisture sensors installed near the plant root zone generate electrical signals corresponding to changes in soil water content. These signals are acquired by a microcontroller and processed according to predefined irrigation criteria. When the measured soil moisture falls below the selected threshold, the controller activates the irrigation actuator and supplies water to the plant. When adequate moisture is restored, the actuator is switched off. Such feedback-based control establishes a closed-loop irrigation mechanism in which the irrigation operation responds to the actual condition of the soil rather than relying exclusively on a predetermined schedule. Bwambale et al. (2022)

highlighted the importance of real-time monitoring and closed-loop control strategies for improving irrigation scheduling and water-use efficiency.

Integration of environmental sensors further improves the reliability of automated irrigation. Rainfall information provides an additional decision parameter because irrigation during or immediately after rainfall results in unnecessary water application. Temperature and relative humidity measurements provide information about atmospheric conditions associated with plant water demand, while light intensity obtained from an LDR provides an indication of the prevailing illumination level. Atmospheric pressure measurements from a BMP180 sensor provide supplementary environmental information for system monitoring. Nsoh et al. (2024) reported that modern IoT-based irrigation systems increasingly integrate multiple sensor sources with automated control and data-processing frameworks to improve real-time irrigation management. The integration of multiple sensing parameters therefore provides a more comprehensive representation of garden conditions than soil moisture monitoring alone. Wireless communication further extends the functionality of automated irrigation systems by enabling remote monitoring and user interaction. The NodeMCU ESP8266 provides a compact microcontroller platform with Wi-Fi connectivity, making it suitable for transmitting sensor data to an online platform and receiving user commands through a network-connected application. An IoT-based architecture establishes communication between the sensing layer, control unit, irrigation actuator, data-storage system, and user interface. Such an architecture supports continuous observation of garden conditions and facilitates remote supervision without requiring the user to remain physically near the garden. Obaideen et al. (2022) described IoT, smartphone-based interfaces, and sensor networks as important components of smart irrigation systems for real-time monitoring and automated agricultural operations. The proposed Plant Watering System for Home Gardens (PWSHG) is developed as an integrated sensing and control platform for automated irrigation in residential gardens. The system incorporates soil moisture sensors as the primary irrigation decision sensors, together with a rain sensor, DHT11 temperature-humidity sensor, LDR, BMP180 barometric pressure sensor, and a load-cell-based water measurement unit. A NodeMCU ESP8266 controller processes the acquired sensor information and controls a submersible motor according to the programmed irrigation conditions. The RTC DS3231 provides time information for time-stamped operation and data logging, while an SD card provides local storage of system observations. The LCD provides local display information, and wireless communication provides remote monitoring and control. The load cell integrated with the HX711 module provides measurement of water quantity associated with the irrigation process, enabling quantitative assessment of water utilization.

The proposed system therefore combines real-time sensing, threshold-based irrigation control, water-use measurement, data logging and IoT communication within a single home-garden platform. The present implementation focuses on sensor-based automated irrigation rather than machine-learning-based prediction. The recorded environmental and irrigation datasets provide a foundation for subsequent development of AI and machine-learning algorithms for predictive irrigation scheduling and plant-water requirement estimation. Recent research indicates that integration of IoT-generated sensor data with machine-learning methods represents an important direction for advanced irrigation management and predictive water-need estimation (Togneri et al., 2023; Nsoh et al., 2024). The aim of the present work is to design, develop and experimentally evaluate an IoT-enabled automated plant watering system for home gardens using NodeMCU ESP8266. The developed system is intended to detect soil-water conditions, identify rainfall events, monitor environmental parameters, automatically operate the irrigation motor, record water-use information, and provide local and remote access to system data. The design emphasizes low-cost components, modular operation, reduced manual intervention, and efficient utilization of irrigation water.

2. Literature Survey

The application of automation and Internet of Things (IoT) technologies in irrigation has received considerable research attention because of the increasing requirement for efficient water management and real-time monitoring. Obaideen et al. (2022) reviewed IoT-based smart irrigation systems and reported that the integration of soil and environmental sensors with automated control improves irrigation management by providing continuous information about soil moisture and weather conditions. Their review identified soil-moisture monitoring, wireless communication, automated actuation, and remote supervision as important components of smart irrigation architectures. The use of sensor-based irrigation shifts the control strategy from fixed irrigation schedules toward condition-based water application. Several researchers have developed automated irrigation systems based on soil-moisture sensing and microcontroller-controlled water pumps. A smart irrigation system reported in 2022 incorporated a soil-moisture sensor, temperature sensor, and water-flow sensor with a microcontroller and pumping motor. The system automatically switched the pump according to the measured soil condition and recorded the acquired data for subsequent analysis. This approach demonstrated the suitability of low-cost embedded electronics for automated irrigation in small gardens, nurseries, and greenhouse applications. The development of IoT-enabled irrigation systems has further introduced wireless communication and remote monitoring capabilities. Ali et al. (2022) developed an irrigation system using an ESP8266 microcontroller and soil-moisture sensing, in which the irrigation pump was controlled according to a predefined moisture threshold. The system transmitted sensor information through a mobile application, providing remote monitoring and control. This type of ESP8266-based architecture is particularly relevant to residential irrigation because the controller combines embedded processing with Wi-Fi connectivity in a compact platform. The use of multiple environmental parameters has also become an important aspect of smart irrigation research. Obaideen et al. (2022) emphasized that soil moisture alone does not represent all factors influencing irrigation requirements and highlighted the importance of integrating soil and weather information. Parameters such as temperature, humidity, rainfall, and solar radiation provide additional information for determining irrigation conditions. Multi-sensor systems therefore provide a broader environmental representation and support more informed irrigation decisions than single-sensor arrangements. The integration of IoT with machine learning has expanded smart irrigation from simple threshold-based automation toward predictive irrigation management. Togneri et al. (2023) reviewed data-driven approaches for irrigation decision-making and highlighted the importance of sensor-generated data for estimating water requirements and improving irrigation scheduling. Their work demonstrated the growing role of IoT data, environmental monitoring, and predictive models in intelligent irrigation systems. IoT-based data acquisition therefore provides the infrastructure required for subsequent development of predictive irrigation algorithms. Recent research has examined the application of machine-learning algorithms specifically for smart irrigation. A systematic literature review by the authors of The Application of Machine Learning Techniques for Smart Irrigation Systems analyzed 55 studies published between 2017 and 2023 and identified several machine-learning approaches used for irrigation prediction and decision-making. The review reported that machine-learning techniques demonstrate strong potential for irrigation management, while also identifying limitations related to dataset quality, generalization, and the relatively limited deployment of validated models in practical irrigation systems. Nsoh et al. (2024) presented a systematic review of IoT-based automated irrigation systems incorporating machine learning. Their analysis considered the complete irrigation-management pipeline, including sensor-based data collection, communication, processing, decision-making, and water application. The study emphasized the importance of integrating multiple sensor sources and identified interoperability, standardization, cybersecurity, and scalability as important challenges for fully automated irrigation systems. These observations support the development of modular systems in which soil, weather, irrigation, and water-consumption information are acquired within a common control framework. Machine-learning-based irrigation decision-making has also been reviewed by researchers focusing on crop water requirement prediction. The literature indicates a transition from irrigation decisions based primarily on visual assessment and fixed schedules toward decisions supported by predicted crop water requirements. Machine-learning models use combinations of soil, climatic, and crop-related variables to support irrigation scheduling and water-demand estimation. However, model performance depends strongly on the quality, quantity, and representativeness of the training data (2024). Recent studies also emphasize the importance of combining real-time IoT sensing with automated irrigation control. Nsoh et al. (2024) reported that an effective smart irrigation architecture requires coordination between sensing, communication, decision-making, and water application rather than treating these functions as independent components. Such an integrated architecture provides a suitable foundation for scalable irrigation systems capable of incorporating additional sensors and advanced analytical methods.

Based on the reviewed literature, existing automated irrigation systems demonstrate strong use of soil-moisture sensing, microcontrollers, wireless communication and pump automation. However, many low-cost systems focus primarily on soil moisture and basic pump ON/OFF control, while advanced systems introduce additional environmental sensing and machine-learning-based decision support. The present work addresses this development gap through an integrated home-garden irrigation platform using NodeMCU ESP8266, incorporating soil-moisture sensors, rain sensing, temperature and humidity monitoring, light-intensity measurement, atmospheric-pressure monitoring, water-consumption measurement using a load cell and HX711, RTC-based time stamping, SD-card data logging, LCD-based local monitoring, and Wi-Fi communication. The combination of these functions provides a comprehensive experimental platform for automated residential irrigation and generates time-stamped datasets suitable for subsequent development of predictive and AI-based irrigation strategies. This approach is consistent with the recent research direction toward multi-sensor IoT irrigation systems and data-driven water management (Obaideen et al., 2022; Togneri et al., 2023; Nsoh et al., 2024).

3. Methodology

The proposed Plant Watering System for Home Gardens (PWSHG) was developed as an IoT-enabled automated irrigation system for real-time monitoring and controlled water delivery. The system integrates a NodeMCU ESP8266 microcontroller with soil moisture sensors, rain sensor, DHT11 temperature-humidity sensor, LDR, BMP180 barometric pressure sensor, HX711-based load-cell unit, RTC DS3231, SD card module, LCD display, and a submersible motor. The soil moisture sensors continuously monitor the moisture condition of the plant-growing soil, while the rain sensor identifies rainfall conditions. The DHT11, LDR, and BMP180 provide temperature, relative humidity, light intensity, and atmospheric pressure data, respectively. The NodeMCU ESP8266 processes the sensor outputs and controls the submersible motor according to predefined soil-moisture and rainfall conditions. When the soil moisture decreases below the selected threshold and rainfall is not detected, the controller activates the motor to supply water to the plants Bwambale et al. (2022). The motor is automatically switched off when the required moisture condition is reached. The load cell and HX711 module quantify water consumption during irrigation, while the RTC DS3231 provides time-stamped information for data recording. Sensor readings and irrigation parameters are stored on an SD card for subsequent analysis, and the LCD provides real-time local information to the user. Wi-Fi connectivity enables remote monitoring and control through an IoT-based interface. This integrated sensing and feedback-control methodology provides automated irrigation, reduces manual intervention, and supports efficient utilization of water resources in home gardens (Obaideen et al., 2022; Togneri et al., 2023).

4. Block diagram of developed system

Figure 1 illustrates the block diagram of the proposed Plant Watering System for Home Gardens, consisting of sensing, processing, control, communication, data-storage, and irrigation units. The NodeMCU ESP8266 functions as the central control unit and receives information from two soil moisture sensors, rain sensor, DHT11 temperature and humidity sensor, LDR for light-intensity measurement, BMP180 barometric pressure sensor, load cell with HX711 module for water-quantity measurement, and GPS module. The acquired sensor data are processed by the controller to determine the irrigation requirement of the plants. When the soil moisture decreases below the predefined threshold and rainfall is not detected, the controller activates the motor driver/relay, which operates the submersible motor to supply water to the plants. The motor is deactivated when the required soil-moisture condition is achieved. The RTC DS3231 provides time information for time-stamped measurements, while the SD card module stores the acquired environmental and irrigation data for subsequent analysis. A 16×2 LCD with an I²C interface provides local display of system parameters, and the GSM SIM 900A module provides remote communication and alert functionality. A push button provides manual control of the irrigation operation, while the regulated power supply provides the required electrical power to the system. The integrated architecture establishes a feedback-based automated irrigation system that continuously monitors garden conditions and controls water delivery according to the measured plant-growing environment.

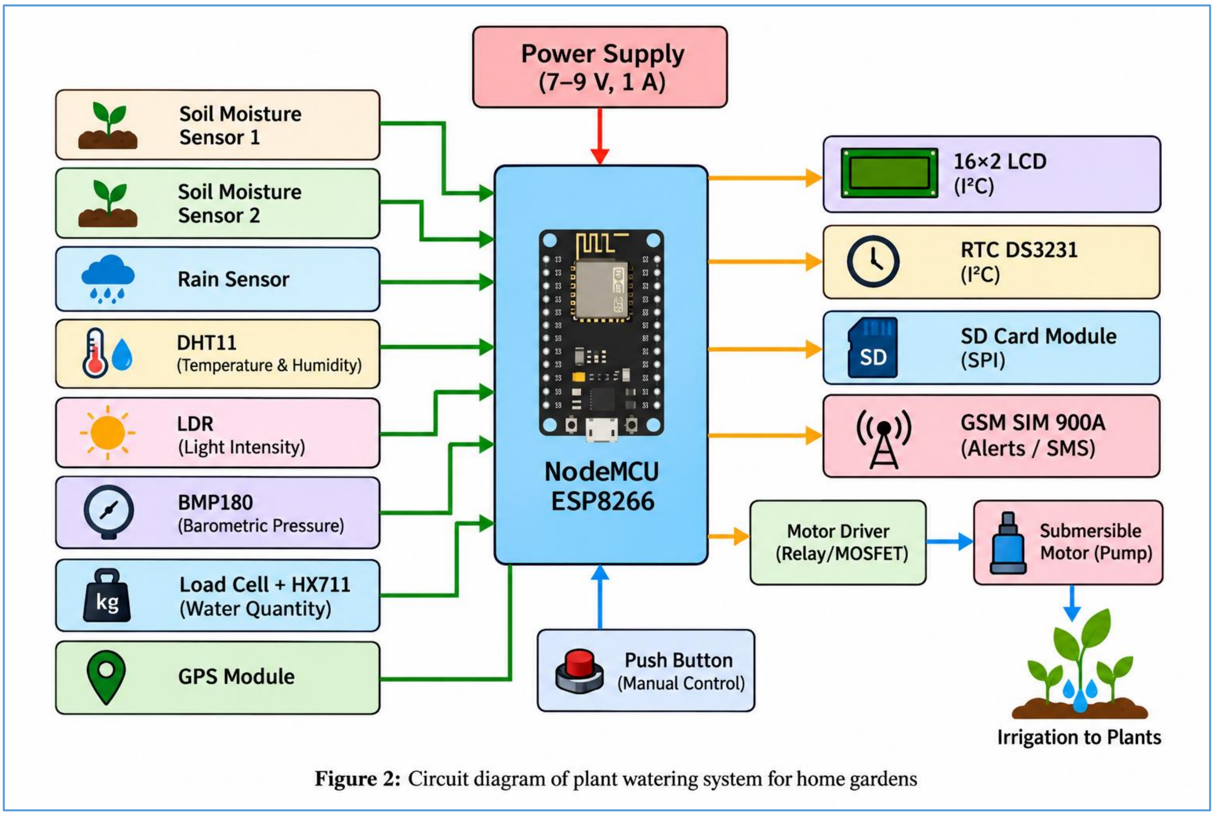

Figure 1: Block diagram of plant watering system for home gardens

5. Circuit diagram of developed system

Figure 2 illustrates the circuit configuration of the proposed Plant Watering System for Home Gardens based on the NodeMCU ESP8266 microcontroller. The NodeMCU ESP8266 functions as the central control unit and interfaces with the different sensing, communication, data-storage, display and irrigation components.

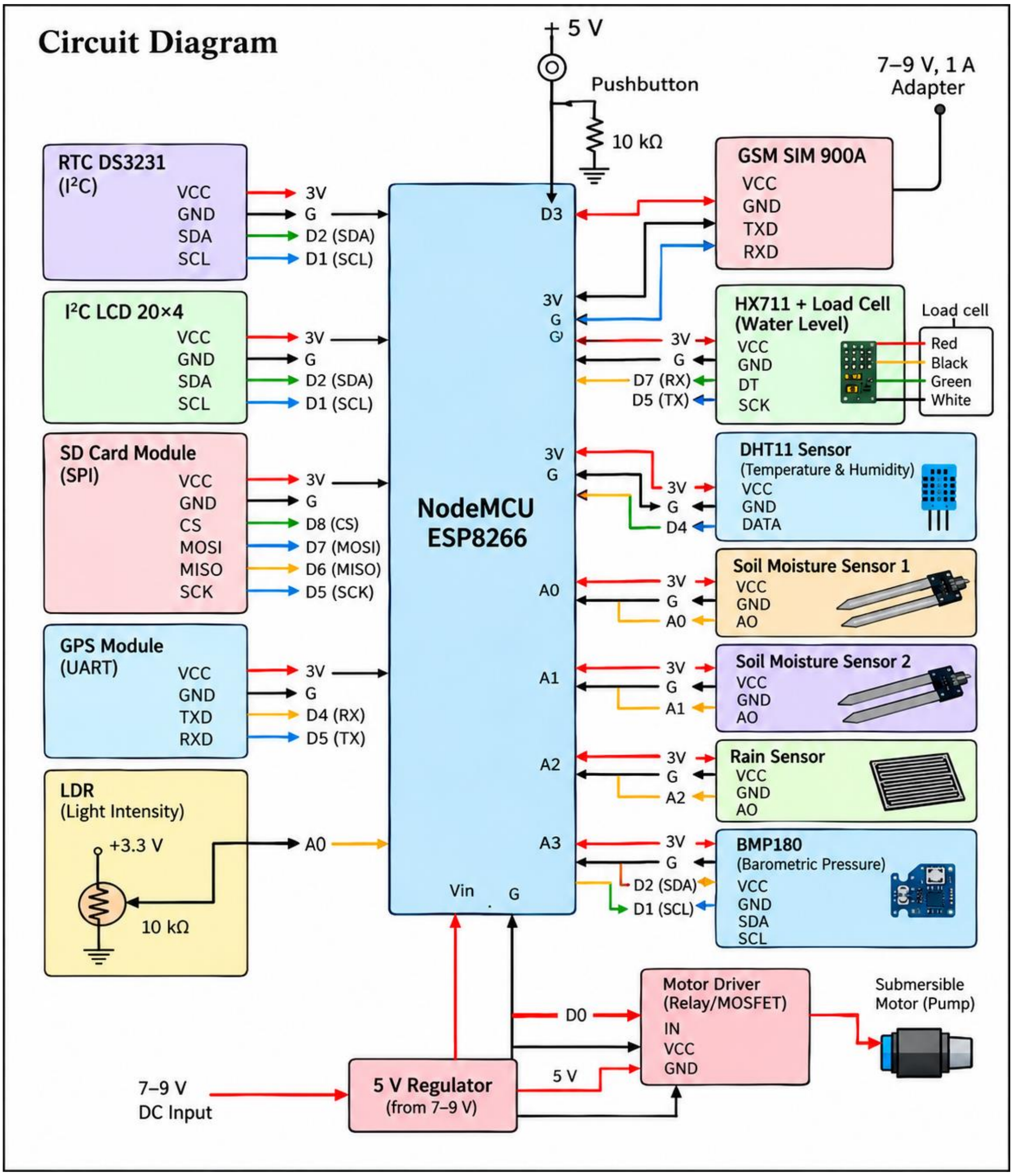

Figure 2: Circuit diagram of plant watering system for home gardens

The RTC DS3231 and I²C LCD are connected through the I²C communication interface for time synchronization and real-time display of system parameters. The SD card module is interfaced with the NodeMCU ESP8266 for storing sensor measurements and irrigation-related data. The DHT11 sensor provides temperature and relative humidity measurements, while the soil moisture sensor continuously monitors the moisture condition of the plant-growing soil. The rain sensor detects rainfall and provides an additional input for irrigation control. The LDR measures the surrounding light intensity, and the BMP180 sensor records atmospheric pressure. The HX711 module connected to the load cell measures changes in water quantity during irrigation. The GSM module provides remote communication and alert functionality, while the push button provides manual user input. The submersible motor is connected through a suitable relay or motor-driver circuit controlled by the NodeMCU ESP8266. When the soil moisture falls below the predefined threshold and rainfall is not detected, the NodeMCU ESP8266 activates the motor to supply water to the plants. The motor is switched off after the required soil-moisture condition is achieved. The NodeMCU ESP8266 also provides Wi-Fi connectivity for IoT-based monitoring and data communication. Thus, the circuit integrates sensing, processing, wireless communication, data logging, user interaction, and automatic motor control into a compact system for efficient home-garden irrigation.

Figure 3: Actual image of developed plant watering system for home garden

Figure 3 presents the actual prototype of the developed Plant Watering System for Home Gardens. The system integrates the NodeMCU ESP8266 as the main control unit with the soil moisture sensor, rain sensor, DHT11 temperature and humidity sensor, LDR, BMP180 barometric pressure sensor, load cell with HX711 module, RTC DS3231, SD card module, LCD display, GSM communication module, and submersible motor. The sensors are positioned to acquire real-time information about soil and surrounding environmental conditions, while the NodeMCU ESP8266 processes the collected data and controls the irrigation operation. The submersible motor supplies water to the plants when the soil moisture level reaches the programmed dry-condition threshold and the rain sensor indicates the absence of rainfall. The developed prototype also incorporates local display, data logging, water-consumption measurement, and communication facilities for monitoring system operation. The assembled prototype demonstrates the practical integration of sensing, processing, communication, and automatic irrigation functions into a single system designed for efficient and convenient home-garden plant management.

6. Major component of developed system

The developed Plant Watering System for Home Gardens (PWSHG) consists of several interconnected hardware components that perform sensing, processing, communication, data logging, water measurement, and automatic irrigation functions. The major components of the developed system are described below.

6.1 NodeMCU ESP8266

The NodeMCU ESP8266 functions as the central control unit of the developed system. It receives signals from the soil moisture sensor, rain sensor, DHT11 sensor, LDR, BMP180, and water-measurement unit and processes the acquired information according to the programmed control logic. Based on the soil moisture condition and rainfall status, the NodeMCU controls the operation of the submersible motor through an appropriate switching or driver circuit. The integrated Wi-Fi capability of the ESP8266 provides wireless communication between the developed system and the IoT monitoring platform, enabling remote observation and control of the irrigation process.

6.2 Soil Moisture Sensor

The soil moisture sensor is the primary sensing element for determining the water condition of the soil. It detects changes in soil moisture and provides an electrical output to the NodeMCU ESP8266. The controller compares the sensor output with the predefined moisture threshold. When the soil becomes sufficiently dry, the controller initiates the irrigation process by activating the submersible motor. After adequate moisture is restored, the motor is switched off. Thus, the soil moisture sensor establishes the feedback required for automatic irrigation.

6.3 Rain Sensor

The rain sensor detects the presence of rainfall and provides an additional input for irrigation control. The sensor output is monitored by the NodeMCU ESP8266 to distinguish dry and rainy conditions. During rainfall, the irrigation motor remains inactive to avoid unnecessary water application. The integration of rainfall detection with soil moisture monitoring improves the environmental responsiveness of the watering system.

6.4 DHT11 Temperature and Humidity Sensor

The DHT11 sensor measures ambient temperature and relative humidity around the garden. These parameters provide information about the surrounding atmospheric conditions and are recorded along with soil moisture and irrigation data. Temperature and humidity measurements support environmental monitoring and provide useful datasets for future development of intelligent irrigation algorithms.

6.5 LDR Sensor

The Light Dependent Resistor (LDR) is used to monitor the intensity of light surrounding the plants. Its electrical resistance changes according to the incident light intensity, and the corresponding signal is acquired by the NodeMCU ESP8266. The measured light information provides an additional environmental parameter for studying variations in garden conditions and their relationship with irrigation requirements.

6.6 BMP180 Barometric Pressure Sensor

The BMP180 is used for measuring atmospheric pressure. The sensor communicates with the NodeMCU ESP8266 through the I²C interface. Atmospheric-pressure data are recorded as part of the environmental monitoring system and provide supplementary information for analyzing changes in surrounding atmospheric conditions.

6.7 Load Cell and HX711 Module

The load cell with HX711 module is used to quantify water consumption during the irrigation process. The load cell detects changes in the mass of the water container, while the HX711 provides signal amplification and digital conversion of the load-cell output. The NodeMCU processes this information to determine the quantity of water utilized during individual irrigation cycles. This arrangement provides quantitative information for evaluating water-use efficiency.

6.8 Submersible Motor

The submersible motor functions as the irrigation actuator. It transfers water from the storage container to the plants through the irrigation arrangement. The motor is controlled electronically according to the output of the NodeMCU ESP8266. When the soil moisture falls below the predefined threshold and rainfall is absent, the controller activates the motor. When the required soil moisture condition is achieved, the motor is switched off automatically.

6.9 RTC DS3231 Module

The RTC DS3231 provides accurate time information for the developed system. It is used to associate sensor measurements and irrigation events with their corresponding date and time. The time-stamped information is particularly useful for analyzing irrigation frequency, motor operating periods, environmental variations, and water consumption over an extended experimental period.

6.10 SD Card Module

The SD card module provides local storage for the experimental data generated by the system. Sensor measurements, irrigation status, water-consumption information, and time-related data are recorded in a structured format. The stored data provide a permanent experimental record for subsequent analysis and performance evaluation.

6.11 I²C LCD Display

The I²C LCD display provides local visualization of system information. It displays selected sensor readings and operating conditions, such as soil moisture status, environmental parameters, and motor operation. The I²C interface reduces the number of microcontroller connections required for communication with the display.

6.12 GSM Module

The GSM module provides cellular communication and alert functionality. It supports transmission of system-related information to the user through the mobile network. The GSM facility provides an additional communication channel for monitoring irrigation status and important system events, particularly when direct physical access to the garden is unavailable.

6.13 Push Button

The push button provides manual user input to the developed system. It allows the user to initiate or modify selected control functions according to the programmed operation of the NodeMCU ESP8266. The manual input facility provides user interaction in addition to the automatic sensor-based irrigation control.

6.14 Power Supply

The power-supply unit provides the required electrical energy to the controller, sensors, communication modules, and other electronic circuits. Appropriate regulated voltage levels are maintained for the individual components, while the submersible motor is operated through a suitable driver or switching circuit. Proper power management ensures stable operation of the sensing and control circuitry.

7. Software

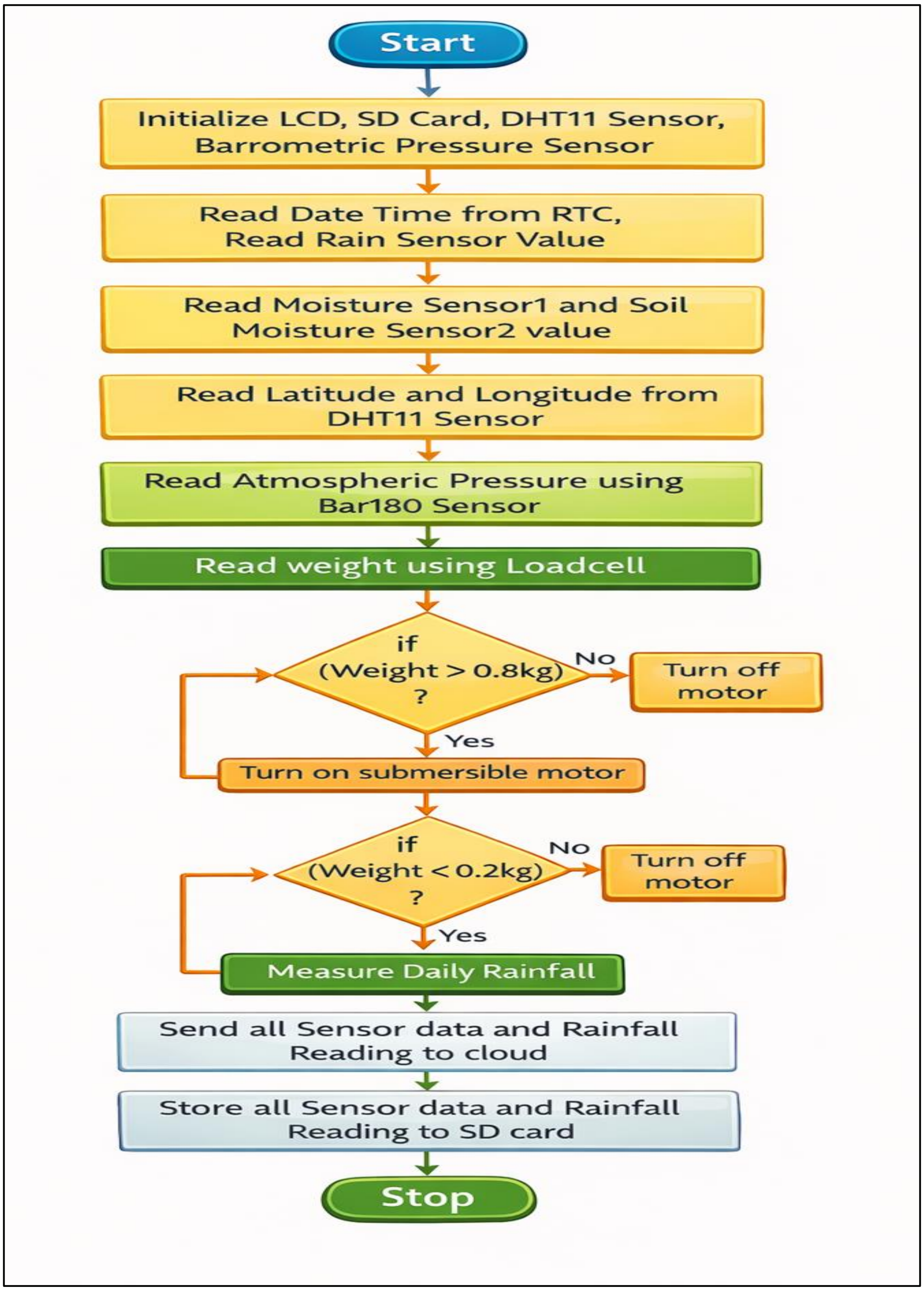

Figure 4: Flowchart of of developed plant watering system for home garden

8. Conclusion

The Plant Watering System for Home Gardens was successfully developed using the NodeMCU ESP8266 as the central control and communication unit. The developed system integrates soil moisture and rain sensing with temperature, humidity, light intensity, atmospheric pressure, and water-consumption monitoring. The system automatically operates the submersible motor according to the measured soil condition and rainfall status, providing controlled irrigation without continuous manual intervention. The integration of the RTC DS3231 and SD card module enables time-stamped recording of environmental and irrigation data, while the LCD and wireless communication facilities provide convenient system monitoring. The load-cell-based water measurement further provides quantitative information regarding water utilization. The developed system provides an integrated, low-cost, and practical approach for automated home-garden irrigation, supporting efficient water management and simplified plant care.

9. Future Scope

The developed system provides a suitable foundation for further advancement toward intelligent and predictive home-garden irrigation. Future development can incorporate Artificial Intelligence (AI) and Machine Learning (ML) algorithms to predict plant water requirements using historical soil moisture, temperature, humidity, rainfall, light intensity, atmospheric pressure, and water-consumption data. Weather forecasting APIs can be integrated to anticipate rainfall and adjust irrigation schedules before irrigation operation. Plant-specific irrigation profiles can also be incorporated to provide different moisture thresholds for vegetables, herbs, flowers, and other plants. Integration of additional sensors such as soil temperature, electrical conductivity, pH, water-level, and flow sensors can provide more comprehensive monitoring of plant and soil conditions. A dedicated mobile application with graphical visualization, historical data analysis, alert notifications, and remote motor control can further improve user interaction. Solar-powered operation can be implemented to reduce dependence on conventional electrical power and support sustainable operation. The system can also be expanded to multiple irrigation zones, allowing independent control of different sections of a home garden according to their individual water requirements. These developments can transform the present sensor-based system into a predictive, adaptive, and fully intelligent home-garden irrigation platform.

Acknowledgment

The authors sincerely express their gratitude to Maratha Vidya Prasarak Samaj's K. K. Wagh Arts, Science and Commerce College, Pimpalgaon (Baswant), Nashik, India, for providing the necessary laboratory facilities, institutional support and encouragement to carry out the present research work successfully. The authors also acknowledge the support and cooperation extended by the teaching and non-teaching staff during the development and testing of the plant watering system.

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