

# IoT-Enabled Water Management: A Low-Cost Framework for Sustainable Irrigation in Agricultural Farms and Home Gardens

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**Abstract**— Agriculture is a major contributor to Bangladesh's economy, with many people depending on it for their livelihoods. Farming and gardening are considered a key initiative in mitigating global warming as well as providing economic support for many families in Bangladesh. However, the vulnerability of gardens to damage during long weekends and vacations necessitates smart solutions. Also, proper irrigation is crucial for agriculture-based farms to thrive, as it is highly dependent on environmental conditions. This paper explores the application of Internet of Things (IoT)-based smart technologies as a promising solution to address this issue. A user-friendly, low-cost system facilitates the commercialization of such solutions on a large scale. In this work, we have implemented an IoT-based solution for the irrigation and watering system for agricultural farms and home gardens in Bangladesh, respectively. Considering the diverse weather conditions of Bangladesh, three key parameters, such as moisture, temperature, and humidity; have been monitored continuously and analyzed in real-time. The proposed system consists of two parts: the watering system, and the mobile app interface. The watering system incorporates an ESP32 Node MCU, sensors, two servo motors and a water pump. In automatic mode the water supply inside the garden or farm is connected to a water pump, that will be activated when the soil moisture sensor detects low moisture level, and the ambient sensor detects low humidity or high temperature. Alternatively, the garden or farm owners can remotely control the pump motor through the mobile app to water in the farm leveraging sensor data. Also, they can control the water flow angle according to their preferences. Additionally, our proposed system has the potential to save a significant amount of water resources. The system is designed to be universal, accommodating gardens and farms of various sizes and shapes while promoting water conservation.

**Keywords**—IoT, Sensors, Automated Irrigation, Systems Integration, Smart Garden, Cloud MQTT, Mobile Application

## I. INTRODUCTION

Since Bangladesh's economy is agro-based, most of the people in the rural areas are either lightly or heavily engaged in agricultural farming and/or gardening. Nowadays, it is also gaining popularity in urban areas owing to several reasons, such as growing fresh food, generating income, or as a hobby. The government encourages urban farming and community gardens to promote environmental conservation and food security. However, successful gardening requires skill, knowledge, and most importantly commitment because plants require proper care and attention to grow efficiently, and different plants require different environments and nutrients to thrive. A study shows that the participation by a community member in urban gardening projects decreased by 2 to a mere 5% over the years, despite many having shown their initial interest [1]. While some of the projects were successful, some were in doubt about the sustainability of

urban farming. Additionally, interested people often struggle to find time for farming in their hectic urban daily life. Modern technologies are extensively explored to reduce physical and mental stress to improve human's daily activity in various aspects of human life, such as communication, eHealth, home automation, and many more. Similarly, smart farming and gardening are also under extensive research as it is related to our existence.

Plants require water to survive, and the quantity they need is determined by evapotranspiration, which depends on environmental factors such as humidity, temperature, soil, wind, and the plant's characteristics. Watering home gardens using traditional methods is not only time-consuming and wasteful, but it can also discourage gardening. Additionally, monitoring gardens becomes challenging for individuals with busy schedules or those who frequently stay away from home. To address these issues, leveraging the Internet of Things (IoT) and automation emerges as a viable solution. Automation is becoming more prevalent in our world since it involves using computers or mobile phones to monitor and control simple day-to-day parameters. The practice of automating complex tasks can enhance our quality of life. By using IoT, sensors can communicate with each other, which is powerful for automation.

The smart gardening system is an application of automation that can be included in home automation systems, particularly for homes with lawns or gardens. Note that home automation refers to the use of technology to control basic home functions remotely and automatically. Smart farming systems are becoming increasingly important as they optimize water usage, especially in the field of agriculture where water resources are scarce. A smart irrigation system is a system that helps in water conservation by monitoring the site conditions and using that information to apply the right amount and timing of water whereas the traditional gardening system waters plants at regular time intervals, regardless of weather and soil conditions, which can lead to problems. A mobile app connected to the Internet could be developed to simplify garden watering and maintenance. Thus, the idea of this project is to embed technology in gardening and farming activity to help them monitor their garden and at the same time improve their agricultural process which is to control watering the plants via a mobile app through IoT.

In Bangladesh, agriculture and food consumption account for a significant amount of water usage, almost 100 times more than personal use. Notably, irrigation stands as the largest consumer of water resources, using up to 70% of river and groundwater. Several research have already been conducted to analyze the effect of efficient use of water on farming and gardening. An IoT-based smart irrigation system has been developed, allowing farmers to remotely control irrigation using a server and website [2], [3]. However,

excessive watering can wash away nutrients and decrease soil aeration, while inadequate watering could stunt plant development and decrease its quality [4]. Therefore, smart solutions in agriculture are crucial for productivity enhancement and have significantly advanced agricultural production [5]. Automated irrigation systems have been identified as economical in the long term, achieving savings through optimized water usage and reduced monitoring time [6].

There are several automated solutions for the agriculture industry are now available on the market [7], [8]. These systems primarily focus on sensor-based irrigation processes [9], [10]. To build a smart irrigation system, electronic devices that can be controlled by humans and communicate with each other are required. This requires a power supply and technology for communication between devices and humans [11]. Depending on the location of the garden, different technologies are used to build a smart garden. As the choice of technology for a smart garden depends on its location, researchers have explained that different device connectivity technologies are employed based on the garden's location [12], [13]. For gardens located near or within urbanized areas, a local LAN network signal can be utilized. In other cases, the Global System for Mobile Communication (GSM) [14], and mobile devices are necessary to enable fuzzy logic and support Android apps and master irrigation management. Additionally, other communication protocols between IoT devices for smart irrigation are also investigated [15].

If the garden or farm is located outside an urbanized area, it is necessary to have a power supply for the devices, a data transmission channel, and a water source for the watering process itself [16].

A mobile app connected to the internet is developed to simplify plant watering and maintenance. Thus, the idea of this project is to embed technology in gardening and agricultural activity to help them monitor their farms and at the same time improve their gardening process which is watering the plant. An important aspect of this prototype is that it saves costs and ensures safety. When people create gardens, they often neglect them over time, leading to plant destruction. This prototype can automatically monitor parameters and ensure that the garden and agricultural firms are well-maintained, making it a vital companion for plants.

The main objective is to optimize the water supply to crops, reduce manual intervention, and make the irrigation system smart, autonomous, and efficient. This system can be implemented on a large scale for farming purposes, which can prove to be more advantageous. Due to the prevailing conditions and water shortages, optimum irrigation schedules should be determined, especially in farms, to conserve water. It will also benefit users who are interested in researching their plant growth. Moreover, the proposed solution to this problem will help save time, money, and the environment by reducing water loss. The proposed system consists of two main modes: manual and automatic mode.

Numerous researches have been conducted to develop plant watering systems. Many of these systems utilize IoT and sensors to monitor various parameters. However, no system has combined soil and environment sensing with both automatic and manual irrigation systems, as well as controlled water flow direction. This project addresses all of these concerns by incorporating a pump motor and two servo motors that can be controlled via a mobile application from

anywhere. We conducted extensive research to choose the best components for the system in order to optimize water management, reduce costs and power consumption, and keep the system compact. Our system is both effective and user-friendly, with two modes: Manual and Automatic for water supply. The automatic watering system operates based on sensor readings, and we've even included water flow direction control. Users can easily monitor and control the entire system using the smartphone application.

## II. METHODOLOGY

### A. Proposed System

The architectural block diagram of the system is shown in Fig. 1. It includes the ESP microcontroller unit (MCU), which also functions as a Wi-Fi module, a soil moisture sensor, a humidity and temperature sensor, two servo motors, and a water pump motor. The collected data will be transmitted via the internet network and monitored through a smartphone application.

The Node MCU collects environmental data through sensors and sends it to a cloud server. The server updates the data in the user's smartphone application. The user can then decide whether to irrigate their plants or not and can control the direction of the water flow. A pump motor is connected to the system through a relay driver, which irrigates the plants. Additionally, two servo motors are connected to the system through a servo control driver, which is used to control the direction of the water flow. The major hardware components are described in Table I.

A mobile application was created using Android Studio that allows users to monitor the temperature, humidity, and soil moisture of their plants. The app also enables users to control the irrigation system based on the readings. The app displays gauges to show the relative humidity, soil moisture, and air temperature. Switches in the form of on/off button gadgets are used to activate and deactivate the pump depending on the temperature and humidity levels. Additionally, users can adjust the water flow in four dimensions, allowing for precise and efficient irrigation.

TABLE I: HARDWARE COMPONENTS OF THE PROPOSED SYSTEM

Parts Name	Model No	Specification	Qty
Node MCU	ESP32S2	320KB SRAM, 128KB ROM, 8MB PSRAM, 4MB Flash	1
Soil Sensor	FC-28	3~5.0V, 15mA, LM393	1
Humidity Sensor	DHT22	3.3-6V DC, 0-100%RH; 40~80°C	1
Pump Motor	FL-43	230V, 180W	1
Servo Motor	MG996R	360° Rotation	2

### B. System Hardware Components

The proposed system for predicting soil properties consists of four main parts: a data collection part, a data communication and process part, a water delivery system part, and a smart application part with a cloud server. This proposed automated system typically involves the integration of various hardware components to automate and optimize the watering and care of plants. Here's a description of the key hardware components you might find in such a system:

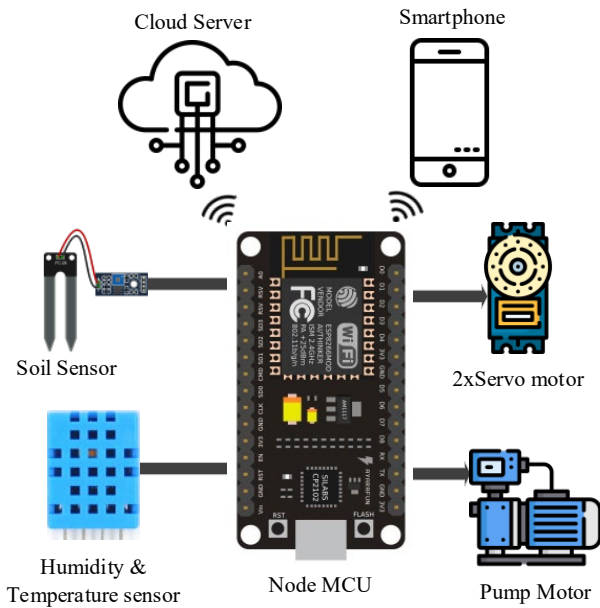


Fig. 1. System block diagram of smart garden/irrigation system

1) *Soil Moisture Sensors (FC-28)*: This device is affordable and user-friendly, designed to monitor soil moisture levels. It uses capacitance to measure the dielectric permittivity of the surrounding medium, which indicates the water content in the soil. These sensors are inserted into the soil near plant roots to measure moisture levels, which helps determine watering frequency and amount.

2) *Temperature and Humidity Sensor (DHT22)*: The DHT22 is an affordable and reliable sensor that measures temperature and humidity using a capacitive sensor and outputs digital signals. Temperature and humidity sensors serve as moisture monitors, preventing overwatering in humid conditions. These intelligent devices function like miniature dehumidifiers, ensuring your plants avoid excess moisture. They monitor ambient air or soil temperature, acting as small yet insightful thermometers that help determine watering requirements.

3) *Controller (ESP32S2FH2 Node MCU)*: Node MCU is a compact system-on-chip (SoC) that includes a 32-bit microcontroller, digitized interfaces, antenna switches, power amplifiers, low noise receive amplifiers, and power channels. This MCU has a built-in Wi-Fi function to send data to the server. This is the brain of the operation, receiving data from all the sensors and using it to control watering based on pre-programmed settings or real-time conditions. It's like the conductor of an orchestra, keeping everything in harmony.

4) *Water Pump System*: A water delivery system is a network of components designed to transport water efficiently from a source to a specified destination. In the context of gardening or irrigation, a water delivery system ensures that water reaches plants in a controlled and targeted manner. There are several parts of the water delivery system as water source, pump, flow control and other peripherals as motor driver, piping and tubing. Water Source is the origin of the water, which could be a reservoir, water tank, well, municipal water supply, or other water storage solutions. A water Pump is an electric motor that pressurizes and moves water from the source through the delivery system. A flow control system is used to spray water in a garden or plant. To

regulate the distance and angle of the spray, a servo motor is utilized.

The network of pipes or tubing that carries water from the pump to the areas where it's needed. Materials can include Polyvinyl Chloride (PVC), polyethylene, or other suitable materials based on the application. A steel-made mechanical frame is utilized to hold two servo motors that control water flow in both up-down and left-right directions. To drive two servo motors a servo driver is used and other hand to power the whole system a power supply is used.

### C. Hardware Design

The hardware design and development of a system involves all the components of the system's hardware. In this particular system, the Node MCU ESP32 microcontroller serves as the main processing unit that handles most of the processes, such as controlling the water pump, processing sensor data, and sending the data to the database. Fig. 2 displays the block diagram and layout of the supporting device of the system. The soil moisture sensor and humidity sensor receive data from the Node MCU ESP32, which is then sent to the cloud server via the internet network. This data is then displayed on the smartphone application. Similarly, data variables taken from the smartphone application are sent to the server first and then can be read by the Node MCU ESP32 on the device. Finally, the pump motor and other peripherals are operated by Node MCU.

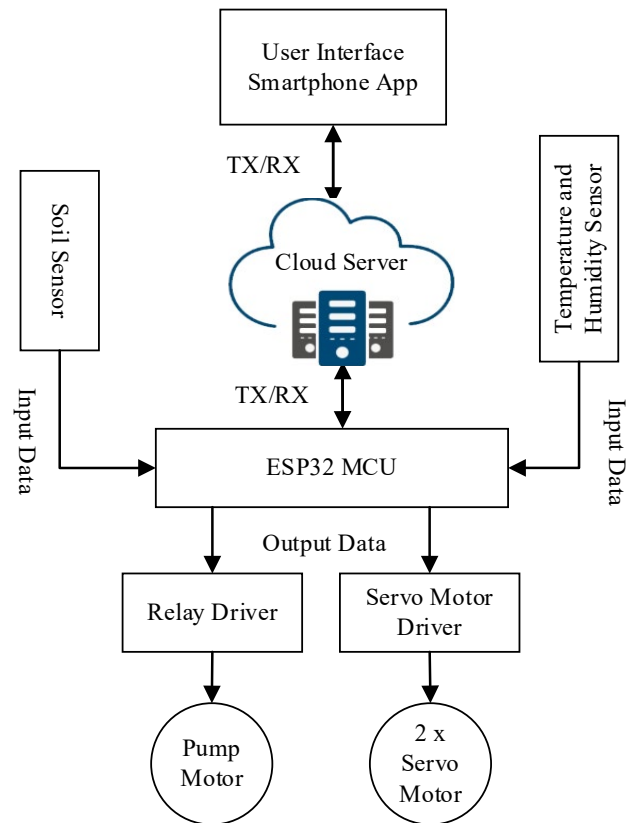


Fig. 2. System hardware architecture

### D. Software design

This system has two parts in software development, one is embedded development another is IoT architecture including smart app development. The embedded design includes data processing on the Node MCU ESP32 microcontroller for the FC-28 soil moisture sensor and DHT22 temperature-

humidity sensor data processing and calibration. Arduino IDE is used for ESP32 embedded design in this architectural system. The data sensed by each sensor is transmitted to the microcontroller. The microcontroller then analyzes the data and sends it to the web server or application. The client can access the results of each sensor from anywhere in the world. Additionally, the data from each sensor can be logged every second for future analysis.

There are five layers involved in the development of IoT in this system [17]. The physical layer comprises the devices that need to be controlled, and sensors are also connected to this layer. The data link layer includes an IoT gateway router, device manager, and various communication protocols. This layer connects the ESP Node MCU to the web server or cloud via Wi-Fi communication. MQTT is used as a private server to store the sensor data, and it also sends data to the end-users upon request. In this system, MQTT one pi falls under the database/server layer. The application and presentation layer consists of web protocols. This layer involves developing a mobile application if the devices are to be controlled and monitored via smartphones. The entire process is explained in detail in Fig. 3.

For Android smartphone app development Android Studio IDE is used. Smartphone applications serve two primary purposes, which are controlling and monitoring tools. This application has two windows one monitors sensor value and by left swipe, another window appears that displays a control panel where model and irrigation can be controlled. The application displays data that can be monitored from anywhere, as long as there is an internet connection. Additionally, the application allows remote control of the water pump and water flow, which can be turned on and off via a smartphone while connected to the internet.

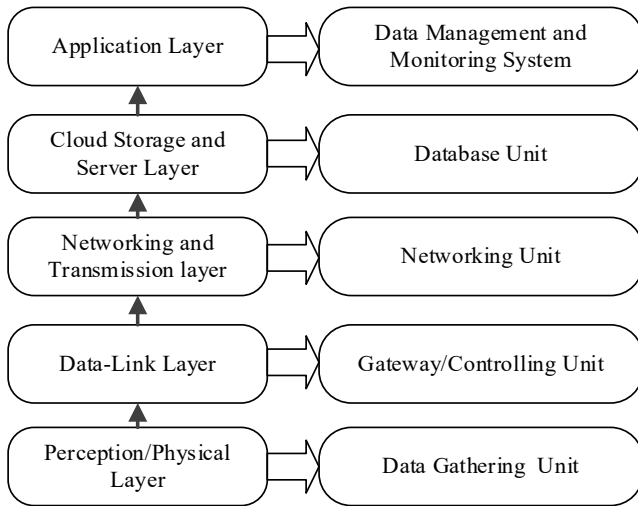


Fig.3. IoT Architecture of the Project

### III. RESULTS AND DISCUSSION

The proposed system was tested in our backyard to verify its effectiveness through extensive experiments. The experiment was conducted in Dhaka, Bangladesh in April 2023 to check the system's feasibility during the intense summer season, characterized by high temperatures and thunderstorms. A real-time implementation scenario is presented in Fig. 4. Fig. 4(a) displays the experimental setup while Fig. 4(b) and Fig. 4(c) show the automatic mode of the

smartphone app interface and real-time temperature, humidity, and moisture values within the app, respectively.

In analog interfacing mode, the FC-28 sensor provides moisture percentage values within a range of 0 to 1023, which the microcontroller maps to a percentage from 0 to 100. Data on ambient temperature and humidity is collected from the DHT-22 sensor using single-bus data communication. All sensor data, including information about the pump motor states, is first transmitted to the cloud server and subsequently relayed from the cloud server to the smartphone application for users to view. It's important to note that the servo motors can operate concurrently with the pump motor. Table II shows the value of sensors and respectively ADC value that node MCU detected before and after irrigation. Since the data from the DHT22 sensor is received from the serial bus, we do not have a direct ADC value and thus receive the ambient temperature and humidity directly. At the initial stage of the test, we found a low soil moisture level of around 67.3% and turned the pump motor and servo motors ON. When water reaches at soil sensor point it detects a moisture level of 100% and then after 30 seconds turns all motors OFF. It should be noted that during this process, the ambient temperature and humidity levels may have slightly changed due to water evaporation from the soil.

TABLE II. SENSORS VALUES DURING PROTOTYPE TESTING

Sensors parameters	Before Irrigation		After Irrigation	
	ADC Value	Actual	ADC Value	Actual
Soil Moisture	648	63.3%	1023	100%
Ambient Humidity	54.5%		57.7%	
Ambient Temperature	31.7°C		31.4°C	

The operation of the proposed system involves two threshold modes: automatic settings on the Node MCU and manual mode. In automatic mode, the watering system in farms and gardens operates automatically based on readings detected by the sensors whereas in manual mode, users can monitor and control all gardens or farms, either locally or remotely, using their smartphone application. Automatic mode is governed by three conditions: (a) soil moisture below 60%, (b) temperature above 40°C, and (c) ambient humidity less than 50%. These values are adjustable by the user as per plant categories and other factors. But in this mode system always prioritizes soil moisture value, if the soil moisture level is higher than 80% it will not irrigate although the other sensor exceeds the limiting value. The Node MCU is calibrated and set with sensitivity values based on these conditions. In this mode, irrigation and a full angle for flow control are configured as ON mode until the moisture sensor detects 100% for 30 seconds. Table III demonstrates the logic of automatic mode.

TABLE III. AUTOMATIC MODE LOGIC

Soil Moisture Level	Ambient Temperature	Ambient Humidity	Irrigation System
≤60%	-	-	ON
≤80%	≥40°C	-	ON
≤80%	-	≤50%	ON
100	-	-	OFF

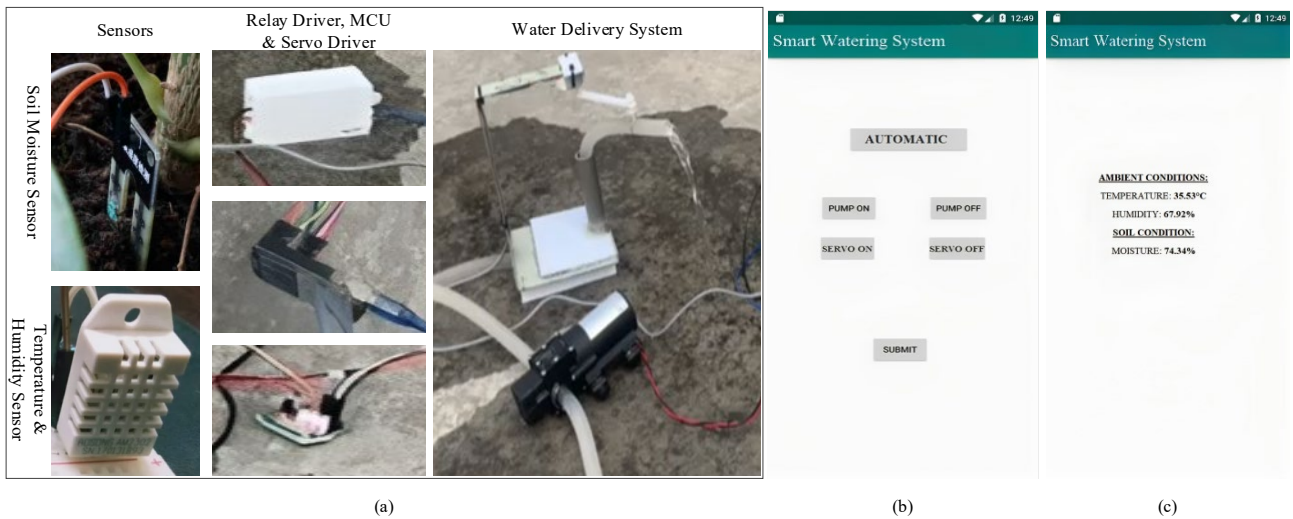


Fig. 4. Prototype testing (a) system field test, app (b) control interface and (c) data interface

#### IV. CONCLUSIONS

In conclusion, the primary objectives of this work have been achieved, providing a well-functioning smart watering system that allows users to efficiently control and automate their garden irrigation. The system's ability to enable users to turn on and off the water pump, set the system parameters, control the water flow angle, and automate modes via a smartphone has been demonstrated. The integration of IoT devices, data, and automation not only meets the immediate needs of efficient irrigation for gardens but also contributes to enhanced water resource management, time savings, and improved plant growth and production. While the current implementation meets the project's initial goals, several modifications, particularly regarding the frame and motor size, will be considered in our future work for real-world applications. Furthermore, the system grants user's flexibility by allowing automation if they prefer not to control it manually. Although the system has shown promise in addressing soil moisture needs during the spring and intense summer, further studies, especially incorporating machine learning algorithms to autonomously respond to sensor data, could enhance its capabilities. This advancement may lead to more sophisticated and adaptive irrigation strategies, contributing to increased efficiency, improved water resource management, time savings, and ultimately fostering enhanced plant growth and production.

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