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Dynamic Simulation Model for Smart Irrigation Using IOT and MCU Technologies

Abdalla M. Elsheikhi[1], Mohammed S. Saleh[2]* and Nadir S. Nabous[3]

[1] Department of Information Technology, Benghazi University, Al- Marj Branch, Libya.

[2]***Corresponding author:** Mohammed.saad@omu.edu.ly Department of Computer Sciences, Omar Al-Mukhtar University, Libya.

[3] National research center for Tropical and Transboundary diseases, Qasr Bin Ghasher, Libya.

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Abstract
The efforts and projects of countries around the sector are coming together with the intention of growing the productivity of agriculture and productivity rates by combining numerous new technologies to enhance and develop the tactics utilized in agriculture. The top priority that requires attention is improving irrigation efficiency in agriculture, because of its unparalleled importance in maintaining sustainable agricultural production. This study suggests a novel approach to lower the amount of water used for soil irrigation, i.e., preserve water and manage water resources as well, which has the potential to effectively increase agricultural sustainability and ensure food security. In fact, the study embraces the concept of 'Smart Agricultural' and the integration of advancing agricultural technologies. Genuinely, the proposed system is built on embedded cutting-edge tools; including the 'Internet of Things' (IoT) and the 'Micro-Controller Unit' (MCU). It is worth mentioning that the working mechanism of the aforesaid developed system, which operates automatically through the embedded MCU or remotely via IoT, is based on the idea that the sprinklers activate when the water level falls below (5) cm meanwhile is cut off when it surpasses (25.0) cm. additionally, the developed system can determine and approve whether the networked devices, IoT components, and MCU can function properly.

Keywords: Smart Agriculture, Smart irrigation System, Internet of Things (IoT), Micro-Controller Unit (MCU), Water Security, Water conservation.

INTRODUCTION

The growing worldwide population and water scarcity, according to (Pathmudi, et al., 2023), make water management in agriculture a crucial concern. Although they have been around for a while, traditional irrigation methods are frequently wasteful and inefficient. in the same vein, (Vadivu, et al. 2023) indicated that crop irrigation can be done more effectively and efficiently using smart irrigation systems, which make use of the newest technological advancements. This literature review's objective is to investigate the body of knowledge regarding intelligent irrigation systems and how they affect the agriculture industry. The significance of water management in agriculture is covered in the introduction of the review. From there, topics include the creation of smart irrigation methods, their elements, advantages, and effects on the atmosphere and the farming industry. In addition to being one of the most important resources for producing food, agriculture contributes significantly to the Gross Domestic Product, which powers any country's economy. However, there are a number of problems with traditional agricultural practices, including significant water waste during field irrigation, reliance on non-renewable energy sources, and resource constraints in terms of time, money, and labor. Today, everything is smart, thus for the country to prosper, the agriculture industry needs to be developed strategically (Kumar, Kumar & Sharma, 2017).

In the same manner, (Vadivu, et al. 2023) said: “The agricultural sector plays a significant role in the economy of many countries, and irrigation is a critical component of successful agriculture. However, traditional irrigation methods can be time-consuming and labor-intensive, and often result in the over or under-watering of crops, which can negatively impact crop yields. To overcome these challenges, smart irrigation systems have been developed to assist farmers in managing their crops and increasing their yield” (Vadivu, et al., 2023: p. 196).

In compliance with (Cui,. 2021), a smart irrigation system is composed of numerous components, such as sensors, controllers, communication gadgets, and client interfacing. Soil dampness sensors are among the foremost vital components of clever water system frameworks. These sensors evaluate the dampness level of the soil and offer information that helps in deciding how much water the plants require. Sensors for sun oriented radiation, temperature, and stickiness are additional components that may be consolidated into brilliantly water system frameworks. Pursuant to (Barriga, et al., 2022), the controller, which modifies the system in response to data collected by the sensors, is another important component of smart watering systems. Data from sensors, controllers, and user interfaces are transmitted over wireless networks or cellular devices. The user interface is the component of the system that enables users to view, interact with, and change system settings as needed. Water, with accordance to (Chamara, et al., 2022) is a resource that crops require to flourish, and managing water resources well is key to getting the best crop yields. More food must be produced with less water due to the world's expanding population. As reported by (Fernando, et al., 2017), According to the Food and Agriculture Organization (FAO), agriculture consumes around 70% of all water consumed globally, and this figure is expected to rise as the world's population grows. As a result, agriculture's efficient use of water is critical to guaranteeing food security and meeting the rising population's food needs.

Besides, food security is highly reliant on agricultural activity to drive the world economy. However, this activity is in great danger due to climatic changes and improper use of irrigation techniques. Consequently, the lives of numerous individuals worldwide are in jeopardy. In light, this paper proposes a smart irrigation system based on the integration of new technologies.

Actually, compared to conventional irrigation systems, smart irrigation systems provide a more effective and efficient means of irrigating crops. In order to maximize irrigation schedules, these systems gather and analyze data from a variety of sensors using cutting-edge technologies, including the Internet of Things. Increased agricultural yields, lower labor costs, less water waste, and better water efficiency are just a few advantages of using smart irrigation systems. Preserving water supplies through The deployment of smart irrigation systems will improve crop quality, benefiting the agricultural business. As a result, smart irrigation systems have the potential to revolutionize how we irrigate crops and provide food security for the expanding global population (Junior, et al., 2023; Delpiazzo, et al., 2023).

The development of smart irrigation systems, as emphasized by (Zamani, et al., 2022; Mahbub, et al., 2021), has been fueled by technological advancements, mainly in the field of IoT (Internet of Things). Data from a range of sensors can be gathered and analyzed by IoT-based systems to optimize irrigation systems. Soil-based and weather-based smart irrigation systems are the two main categories. Weather-based systems employ weather forecasts to change irrigation schedules, whereas soil-based systems use soil moisture sensors to determine when and how much water to use.

Smart irrigation systems offer numerous benefits over traditional irrigation systems, including reduced labor costs, decreased water waste, and increased agricultural output. They consume less water as well. Smart irrigation systems use less water by only delivering water when needed since they have sensors that detect the soil's moisture content. Agricultural harvests are also increased when plants obtain the proper sum of water for growth (Ashlock, 2022).

(Zamani, et al., 2022; Mahbub, et al., 2021) announced that Smart Irrigation Systems (SIS) can save labor expenses because they require less maintenance and monitoring than traditional systems. Intelligent irrigation systems have the ability to benefit both the environment and the agricultural economy. Smart irrigation systems can assist conserve water resources by decreasing water wastage, which is especially important in places with limited water supplies. Furthermore, (Chinasho et al., 2023) noted that by reducing the amount of nutrients and chemicals that leak from the soil, smart irrigation systems can reduce the requirement for fertilizers and pesticides since they allow for precise water distribution. Into the bargain, (Sangaiah, et al., 2023) pronounced that water sources like rivers and lakes may be maintained clean by doing this. The agriculture industry can increase crop yields with the usage of smart irrigation systems, which is significant for assembly the food requirements of the assembling population.

Intelligent irrigation systems, as emphasized by (Katimbo, et al. 2023), can improve crop quality by providing the appropriate quantity of water and nutrients, which can consequence in food that tastes better and is higher in nutrients. This can also raise the quality of the food produced. Higher farm earnings and a more sustainable agriculture sector overall could arise from this.

In this paper, the significance of simulation tools within the context of smart irrigation systems is investigated. It also explored their role in dataset generation, model testing, and validation. As resulting the paper provides a description of a proposed model for simulating a smart irrigation management system using the most recent release of Cisco Packet Tracer. The simulation setup allows for the activation of devices based on certain conditions. It also suggests future uses for the simulation model, such as testing and evaluating a range of agricultural applications. Numerous research works address the advantages of intelligent irrigation systems. These systems optimize water utilization in agriculture through the use of sensors and Internet of Things technology, improving crop quality and quantity. In order to increase irrigation efficiency in smart agriculture, (Gamal, et al. 2023) conducted a review of intelligent irrigation control and monitoring systems. The scheduling and control of irrigation through monitoring techniques have been the foundation of this study. Additionally, a discussion about prospective pathways for future research based on study gaps has been scheduled. It is suggested in this context that open fields be investigated in conjunction with a discrete forecasting control system that uses a combination of soil-based, weather-based, and plant-based monitoring techniques. Open-area agricultural irrigation systems, as opposed to environmentally controlled agriculture research, have unknowns that must be investigated. (Gamal et al. 2023) stated that future research would focus on the development of process dynamics approaches for irrigation systems, as well as the implications of intelligent management and monitoring tactics on irrigation output in open field agricultural systems. In order to address the issues surrounding the design and construction of an Internet of Things (IoT) - based autonomous irrigation system that will greatly reduce the amount of time and money farmers must spend; (Kumar et al,. 2023) conducted a study. There will be less human interaction in the fields. Soil moisture sensors monitor variations in soil moisture, and Internet of Things technology is used to automate irrigation. Because it is so affordable, the suggested technique is best suited for developing nations. The sensor identifies and notifies the node MCU, which turns on the motor, based on the moisture content of the soil. The motor turns off by itself when the plants get enough water. Through his mobile device, the user will receive an alert on the moisture satisfied of the soil. Kumar and colleagues (2023) concluded that their campus has adopted the suggested smart irrigation system, which uses less water and energy. In the same vein, and in order to avoid wasting water resources, (Das et al., 2023) carried out a study with the goal of automating the entire irrigation system in terms of the crop's water requirements by monitoring the soil's moisture content and climate.

The article also discusses how IoT technology allows for remote control of the irrigation system from home. As a result, the system will offer easy access to it and shield the farmer from intense heat and cold. In fact, Das, et al’s study sought to improve a Smart Irrigation System using IoT (Internet of Things) technology. According to Das et al., agriculture is one of the most essential resources for producing food and, because it contributes to GDP, is essential to maintaining the stability of any country's economy. However, there are a number of problems with traditional agricultural practices, including significant water waste during field irrigation and reliance on non-renewable resources like petroleum coal, time, money, and human resources, among others. With the rising need for non-renewable energy sources, automation, and digitization, SMART agriculture is seen as the nation's most promising industry for food production (ibid).

In order to avoid wasting water resources, Kumar, (Kumar, and Sharma's, 2017) study focused on creating a Smart Irrigation System using IoT technology. The goal was to automate the entire irrigation system and provide crops with the necessary amount of water by monitoring soil moisture and climate conditions. According to Kumar, Kumar, and Sharma, farmers will benefit greatly from the new irrigation system as well. It will get easier and more pleasant to irrigate distant areas from home. Furthermore, it will reduce the farmer's time traveling to and from the field in addition to shielding them from the intense heat and cold.

MATERIALS AND METHODS

Simulation Framework: Packet Tracer 7.3, a Cisco Systems tool, is used for modeling smart irrigation systems. It supports network creation, configuration, and troubleshooting. Its user-friendly interface encourages users to learn its functionalities using help documents. It offers a virtual lab for network building practice, network visualization, and cabling skills enhancement. It also ropes IoT device integration for creating smart home networks (Official Packet Tracer Tutorials, 2024). The services provided by the current design include managing the water supply, monitoring field conditions, and making necessary decisions for the virtual agricultural field based on data analysis. The system allows for manual and remote operation via tablet/PC or Smartphone, potentially improving water usage and energy savings. It outlines the steps taken to design and implement the smart irrigation management simulation model. These steps include the selection of smart devices (sensors and actuators), configuration of the microcontroller MCU, gateway, interconnecting devices, and the development of the web interface.

Network Topology: Figure 1 depicts the system design, which consists of three levels. Misra (2021) distinguishes three layers: sensing and actuating, distant processing and service, and application. The functionalities of the various levels of this system are as follows:

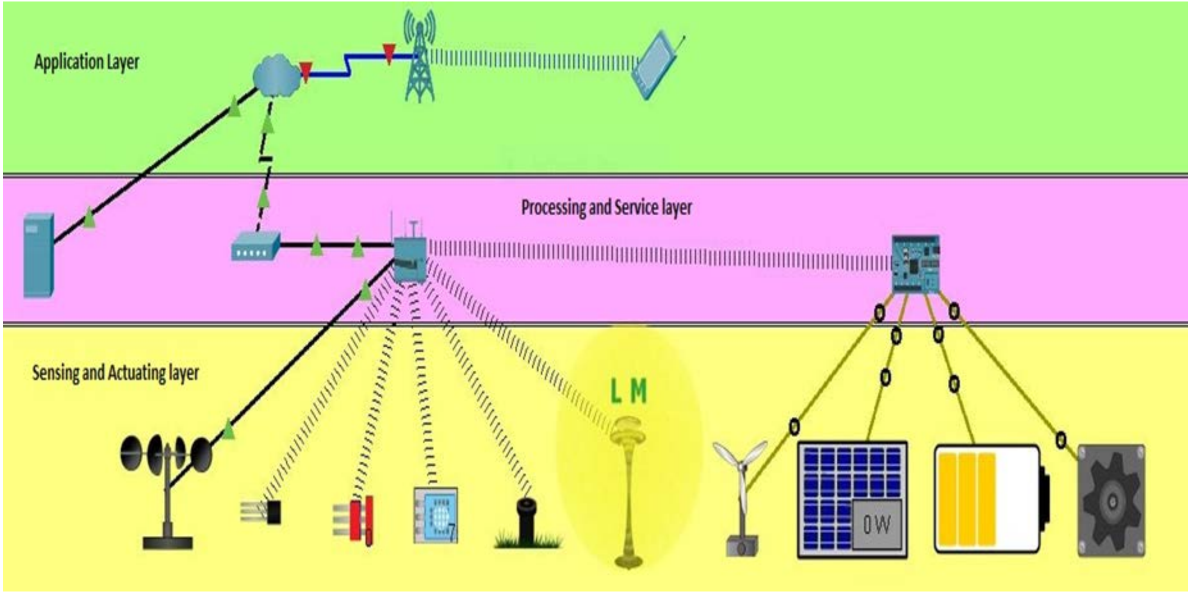

Figure (1). The system design consists three layers

At the sensing and actuating level: various sensor nodes are arranged in the field to measure soil moisture and water levels. Actuators, such as lawn sprinklers and solenoid valves, are installed at this level. Wi-Fi communication modules are used for data collection and irrigation activation as needed.

Processing and Service Layer: Serves as an intermediary, storing and providing access to processed data for future use and remote access by authorized users.

Application Layer: Allows operators to display and control irrigation through cell phones, and an IoT monitor application.

The interconnection of these devices is facilitated by an application programming interface (API), a computing interface that outlines interactions between many software mediators. It provides a platform for the devices to operate and integrates them, fetching information through the cloud (WAN) (Official Packet Tracer Tutorials, 2024). The APIs employed in our work are designed to enhance the functionality of the devices.

The figure 1 illustrates a system consisting of IoT components and interconnecting devices, all connected to the internet. A smartphone is employed for real-time monitoring of field devices. Wireless devices, such as a Home Gateway and IoT devices equipped with wireless modules, are utilized to implement the Wireless Sensor Network (WSN). Table (1) below includes IoT components that are utilized in the proposed network.

These components of IoT can be managed remotely through the Registration Server. Sensors or actuators are registered with the Home Gateway, which provides wireless connectivity. By connecting to the Home Gateway using a web browser application on a PC, devices can be controlled locally. For remote monitoring, configuration, or programming, devices could be connected to a remote IoE Registration Server located on a server. The IoT Registration Service is activated by default via the Services tab on the IoE page of the server device.

Table (1). IoT's components used in WSN

Component	Use
Humidity Monitor	Checks environment values to find the humidity. Registration Server Compatible.
Water Sensor	Senses water level in the soil
Temperature Monitor	Detects and displays the temperature Displays result in a registration server.
Water Level Monitor	Water level detection Registration Server Compatible
Lawn Sprinkler	Raises the water level Registration Server Compatible
Solar Panel	Detects and views the amount of power being generated.
Wind Turbine	Generates electric power
Battery	Shows the percentage of charge left in the battery Registration Server Compatible
DLC100 Home Gateway	Enables wireless interconnecting, Allows end users to monitor, protect and manage their homes using a smartphone, tablet or PC.
Microcontroller (MCU-PT)	Connects and controls things such as sensors and actuators
Motor	Increase or decrease the power controls the engine speed.

Operation of IoT Devices using MCU: The Microcontroller Unit (MCU) is a board used for interconnecting smart things like sensors and actuators. It provides a programming environment to manage the things connected to it. This is crucial for the operation of the hardware as shown in Fig.2. The primary function of this MCU is to activate the system, specify actions, display the water level on the LCD, activate sprinklers, and support detection to achieve specific goals.

The programming for IoT devices, including the water level monitor and lawn sprinklers, was done by Integrated Development Environments (IDEs) specific to each device. Writing code and uploading it to the board were straightforward tasks.

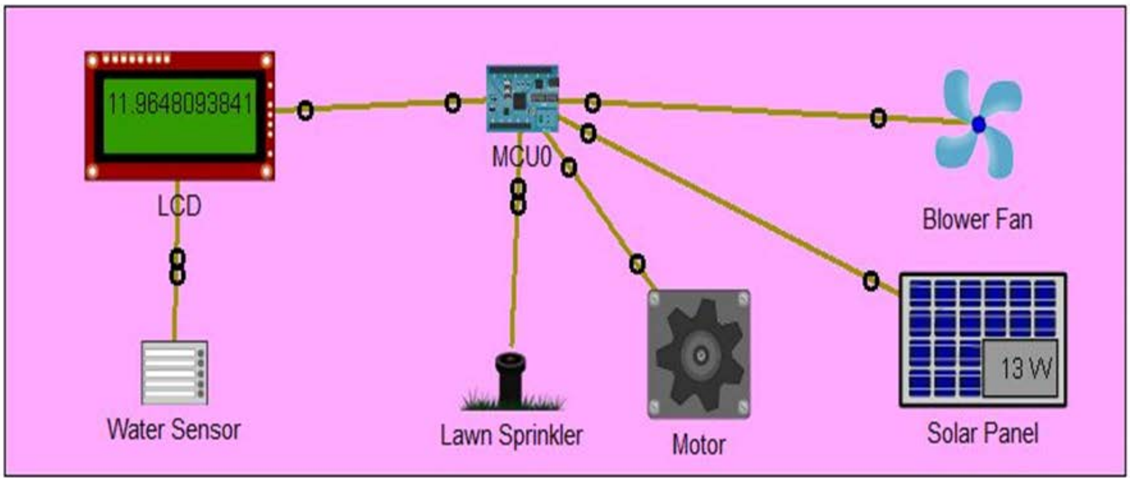

Figure (2). Integrated Development Environments

RESULTS

The proposed architecture on which the simulation is applied, stands for an agricultural field that is divided into subfields as seen in (Figure 3)

Figure (3). An agricultural field that is divided into subfields

The IoT irrigation method is reasonably segmented into three zones: the agricultural field sensors and actuators, Internet service provider servers' central office server and IoT Registration Server, and end-user devices, as illustrated in Figure 4. Upper-side sprinklers, water level monitor, humidity monitor, temperature monitor and solar panel are wirelessly connected to the home gateway.
The home gateway uses a DSL connection to send data to the cloud. This data is stored on servers and can be accessed by end-user devices via cell towers and wireless networks. The home gateway's internet settings include the wireless Service Set Identifier (SSID) and password. All wireless devices utilize the same SSID, password, and DHCP default settings.

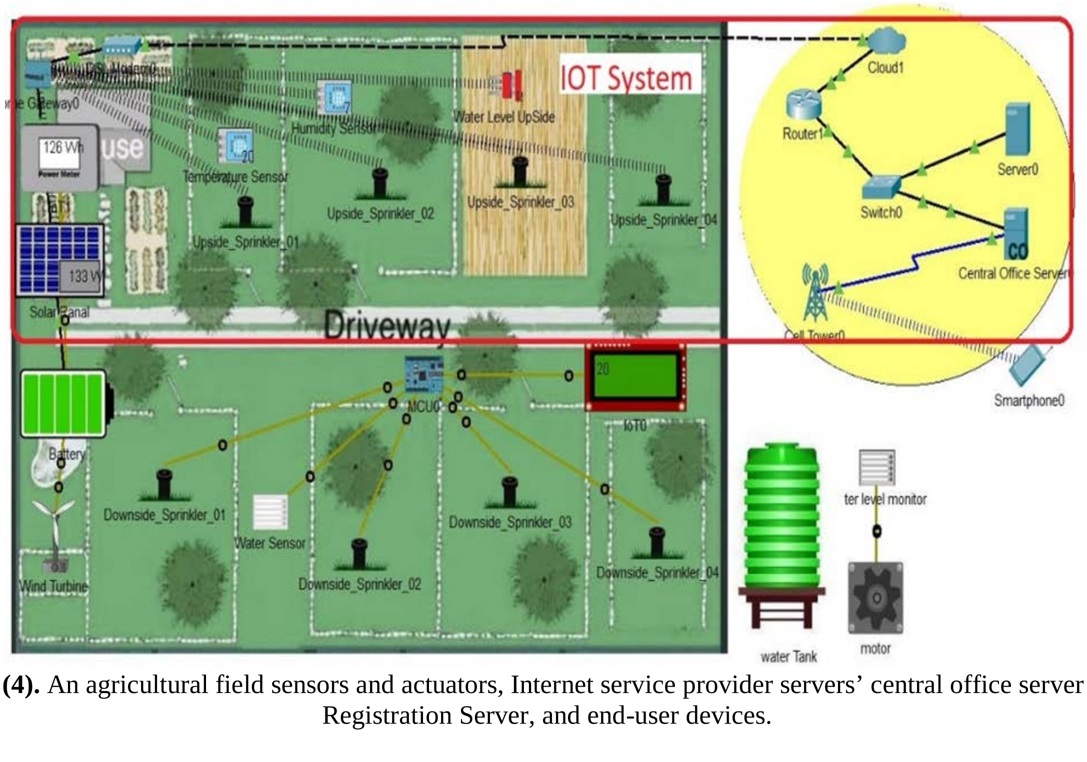

Figure (4). An agricultural field sensors and actuators, Internet service provider servers' central office server and IoT Registration Server, and end-user devices.

IoT devices are remotely connected to the IoT registering server. This connection allows operators to check the position of the IoT devices from an IoT browser site as shows in (Figure 5).

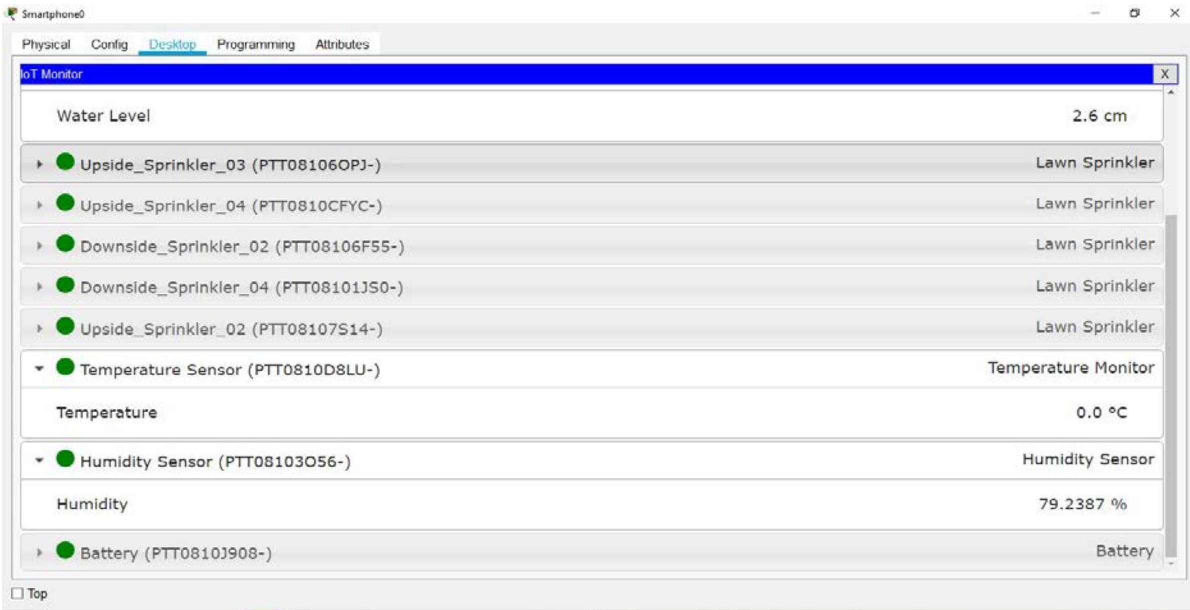

Figure (5). Checking the status interface of the IoT devices

For setting irrigation water level rules, the researchers used Python programming. Figure 6 shows the flawed chart of irrigation water level processing. This processing is includes 4 steps as following:

Initially, the sensors detect their particular parameters based on pre-set conditions.
The sensed values which are analog such as water Level (A0) are then digitized (x).
The current analog water level A0 from sensor, which gives values from 0 to 255, which will be mapped to 0 to 20 cm using the Interpolation formula (where X means original water level):

$$x = 0 + \frac{(A0 - 0) * (20 - 0)}{(255 - 0)}$$

$$x = \frac{20 * A0}{255}$$

These formatted values are subsequently supplied to the actuators. The actuators are triggered based on the input received, adhering to predefined situations, as depicted in Figure 4 below. In an irrigation system, the sprinklers are activated once the water level falls below 5 cm and turn off when the water level exceeds 25.0 cm.

The homepage shows a list of smart gadgets, displays their status, and allows for remote interaction with them. Logical interactions between smart devices can be set up while connected to the main IoT portal. These interactions are based on predetermined conditions, such as activating the sprinkler when the water level in a specific region drops, or lowering the water level in the tank that powers the solenoid valve, as seen in figure 7 below.

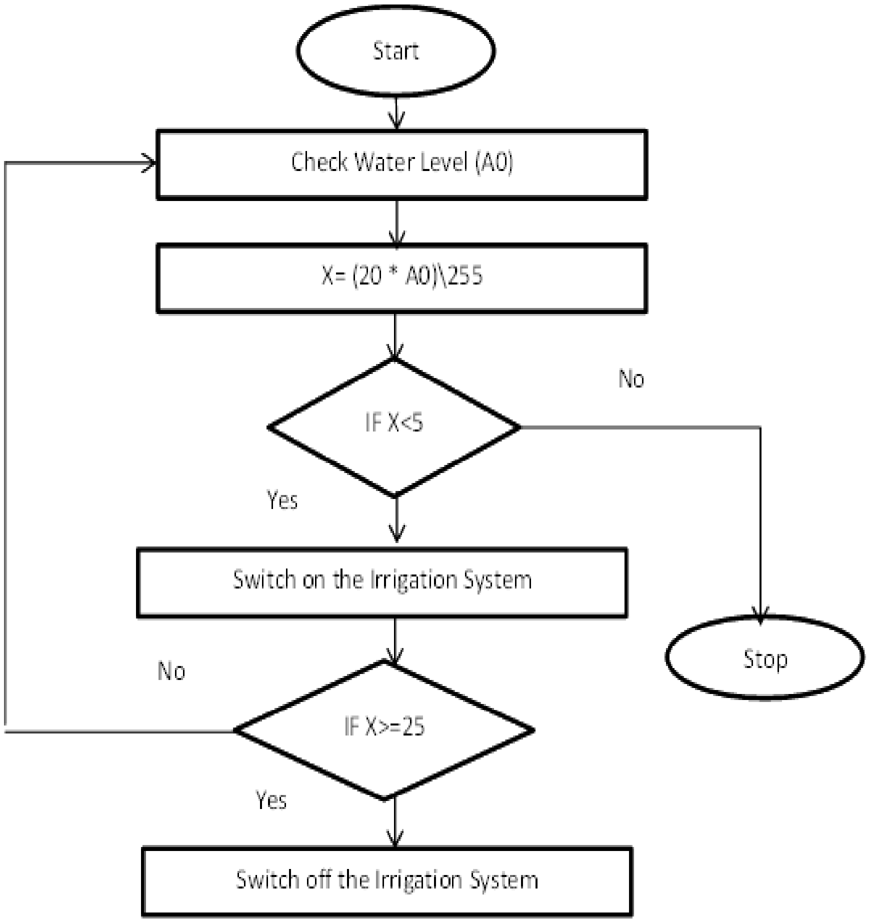

Figure (6). Flaw chart of the flaw chart of irrigation water level processing

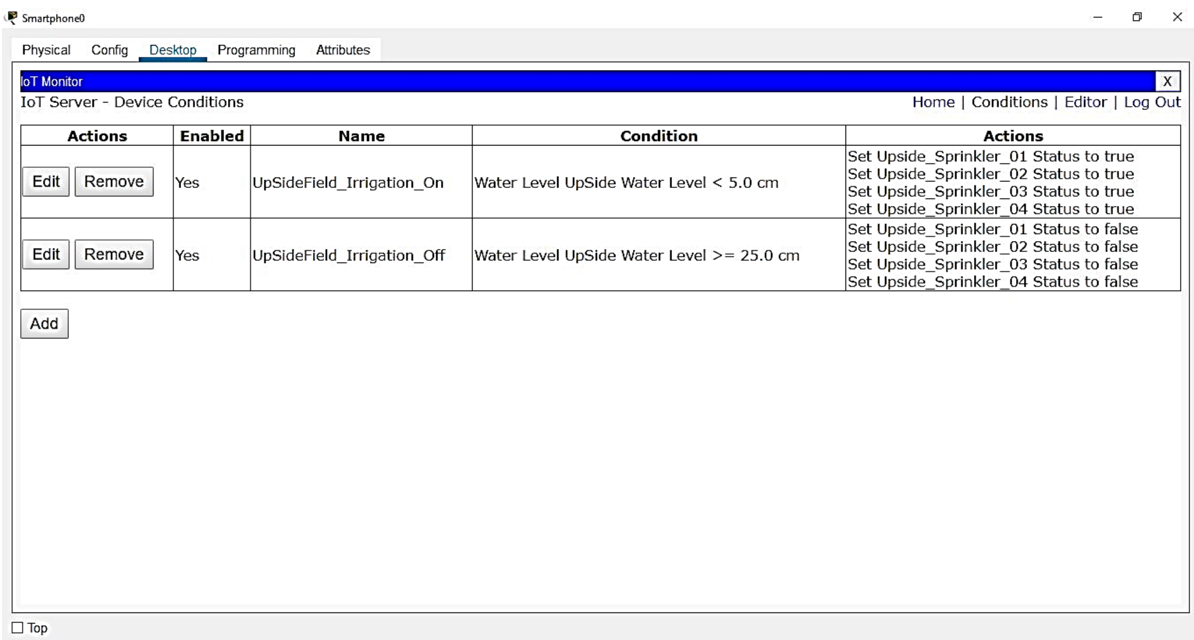

Figure (7). The rules base interface for water level in the tank

Network Interconnection: The network Gateway serves as a central hub for all devices within the system, establishing wireless network links. It enables the interconnection between a Local Area Network (LAN) and a Wide Area Network (WAN), using a DSL modem. This is the point of convergence for all devices and Internet of Things (IoT) components as indicated. In this configuration, a single Home Network Gateway was set up. The assigned IPv4 address is 192.168.25.1, which is typically the default IP address for the home gateway, and the subnet mask is set to 255.255.255.0. The authentication process is stopped while the Service Set Identifier (SSID) is renamed to "Farm-Gateway", aligning with the server's username as depicted in (Figure 8).

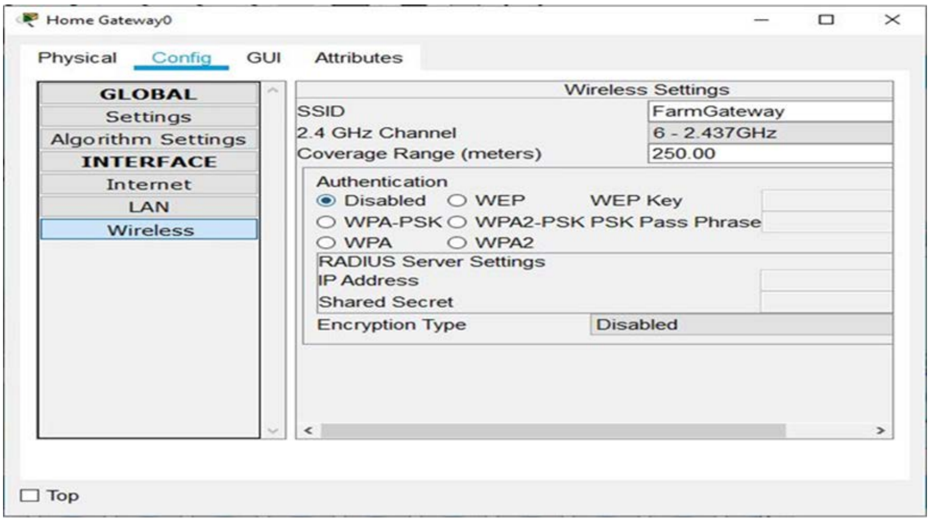

Figure (8). The Farm gateway interface

In this project, all IoT devices are connected to the home gateway with the server-generated username and password. The IoT server is given a static IP address that remains consistent, removing the need to reconfigure devices with new IoT server IP addresses, as shown in figure 9. It offers DHCP services, IoT, and DNS functionality. These features enhance the IoT simulation's backend intelligence and make it easier to host the IoT webpage, from which end users may connect and interact with the smart irrigation system. The DNS service transforms the IoT homepage URL into the IoT server IP address.

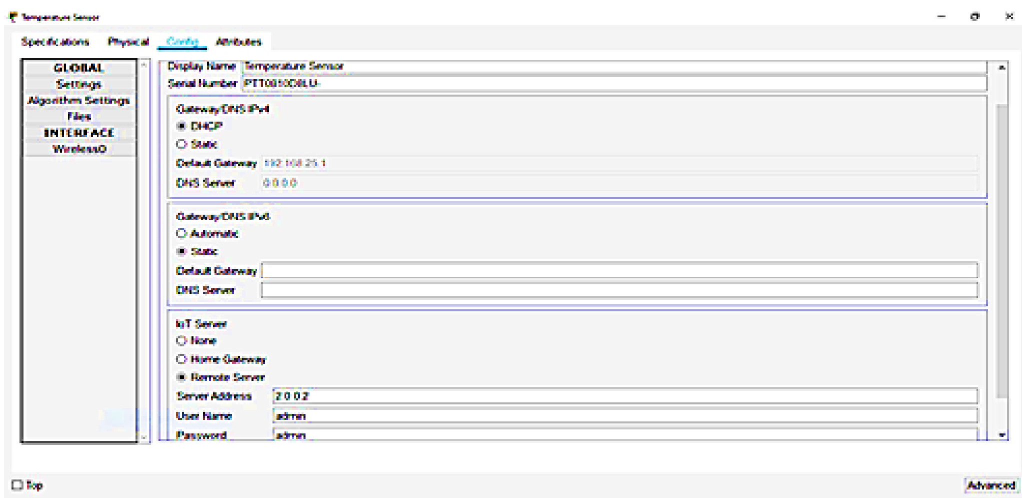

Figure (9). DHCP, IoT and DNS services interface

IoT is also used in smart irrigation systems which can enhance agricultural productivity while conserving water resources. By leveraging data-driven perceptions, these systems contribute to sustainable and efficient farming practices. Smart irrigation management systems use wireless sensor networks (WSN) and the Internet of Things (IoT) to optimize water use efficiency in the agricultural sector (Difallah, 2018**;** Misra, 2021). The systems rely on sensors to provide simultaneous information on environmental situations such as temperature and soil moisture levels, allowing for the optimization of irrigation schedules and well-organized use of water resources. The integration of wireless sensor networks (WSN) and the Internet of Things (IoT) can address these challenges by providing continuous real-time information on soil moisture, temperature, weather conditions, and other parameters to optimize irrigation schedules. This allows for efficient water use and can also reduce labor and energy costs for farmers. Moreover, it can help to prevent over-irrigation and water waste and reduce the negative ecological impact of traditional irrigation on soil fertility and groundwater depletion. Additionally, these technologies can also help to enhance crop yield and the quality of crops grown (Khan, 2013). Simulation tools are essential for testing and evaluating system performance during the development of smart home systems (Dogman, 2020). According to (Sadek, 2023), simulation tools like Cisco Packet Tracer can be used to test and assess a range of smart home applications, including energy management, health monitoring, and home security (Gwangwava, 2021) discusses an industrial use case for an IoT-based smart stimulant manufacturing vegetable that was implemented using Cisco Packet Tracer. Notably, simulation tools have emerged as valuable assets in this domain. They allow researchers to create synthetic environments for testing and assessing a wide range of smart home applications, including energy management, health monitoring, and home security. Various implementations of smart irrigation systems are discussed, such as automated drip irrigation systems, remote monitoring systems, and intelligent irrigation management systems.

Traditional irrigation practices face countless challenges such as water waste due to over-irrigation, lack of real-time monitoring and control of water usage, and inefficient water management. It is a labor-intensive (Khan, 2013). Furthermore, the data on soil moisture, weather conditions, and other factors relevant to irrigation can create more challenges. This can lead to lower crop yields and higher costs for farmers (Suba, 2015).

In this paper, the significance of simulation tools within the context of smart irrigation systems is investigated. It also explored their role in dataset generation, model testing, and validation. As resulting the paper provides a description of a proposed model for simulating a smart irrigation management system using the most recent release of Cisco Packet Tracer. The simulation setup allows for the activation of devices based on certain conditions. It also suggests future uses for the simulation model, such as testing and evaluating a range of agricultural applications.

DISCUSSION

Figure 10 illustrates how Cisco Packet Tracer features move between real-time and simulation modes. The real-time mode enables the establishment of the underlying network, the connecting of IoT devices, and the construction of IoT backend logic. However, only the simulation mode allows for validation of the network communication layer between devices. This mode simulates packet traffic between nodes and devices to verify connection, routing protocols, and other network logic. It aids in the physical visualization and debugging of any network, such as configuring pings or more complicated packets between nodes.

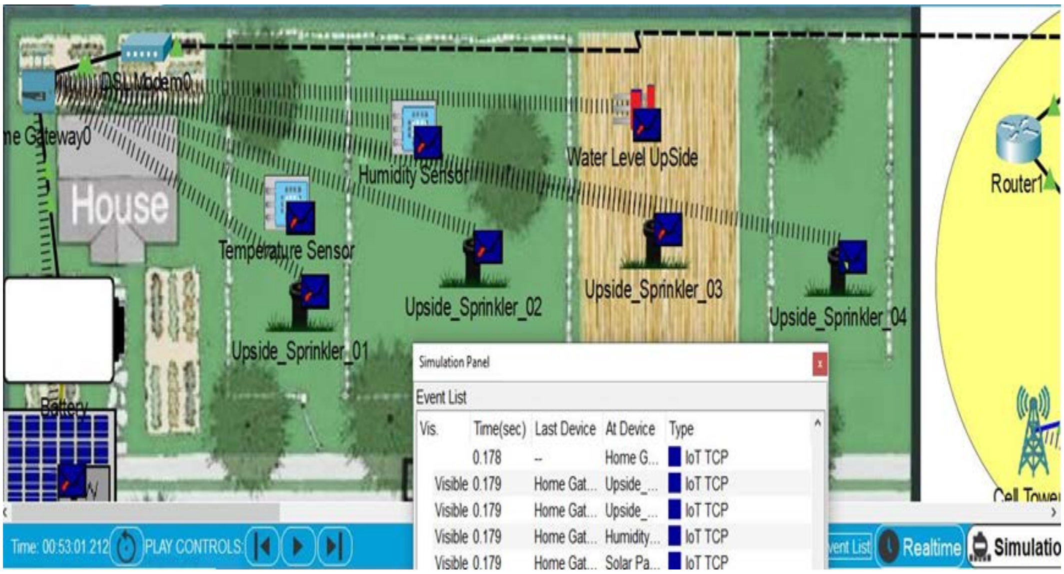

Figure (10). Run real-time and simulation modes**.**

Network Echo Test : This examination is conducted to confirm if the interconnected devices and IoT components are part of the same WSN/internet, demonstrating their ability to interact. As per the above Network Echo Test, all IoT devices and other network elements are connected and work well. It is also possible to control the sprinklers and water valve locally through the digital and analog ports using a microcontroller. The microcontroller is wired to the lower-side sensors, LCD and water Level sensor. The MCU sends an on or off command to the sprinklers, depending on the water level. Additionally, it's probably to control the lower-side sprinklers locally through the digital ports, as illustrated in the figure below.

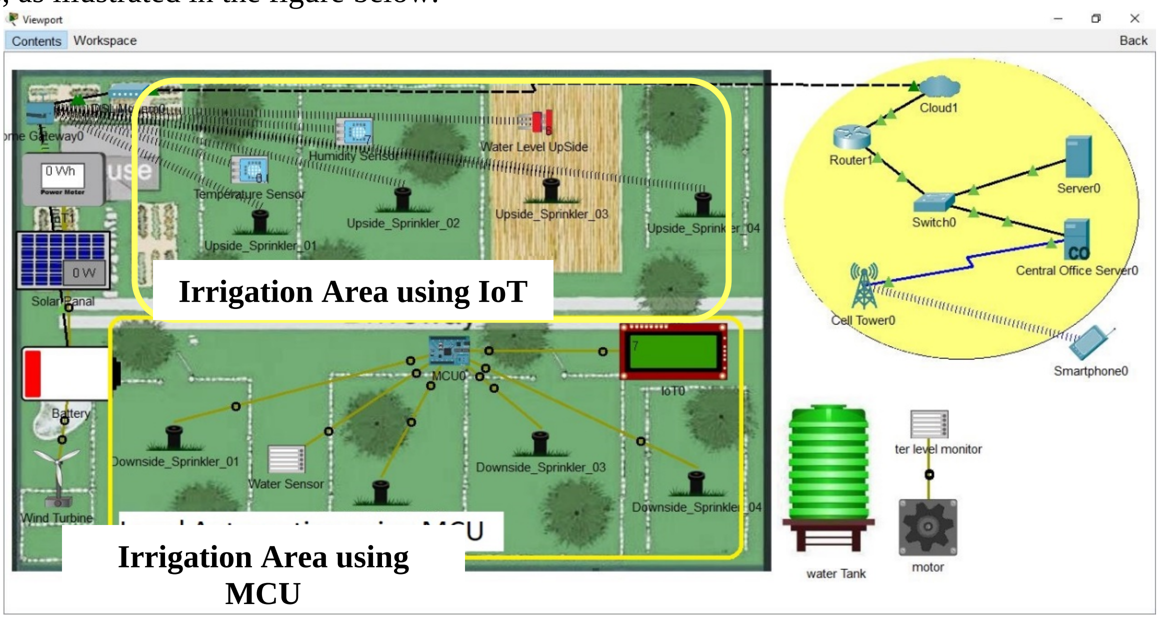

Figure (11). The developed system for smart irrigation farm

The developed simulation of the smart irrigation system has been tested and worked successfully. This system can be used now for real-time monitoring and control of the actuators, ensuring quality, safety, and efficiency. As a result, all devices within the system are monitored through a smartphone as IoT or MCU systems. Both developed systems show a significant outcome as seen in the following results:

Water Level Monitoring: The sprinklers are activated when the water level falls below 5 cm and are turned off when the water level exceeds 25.0 cm.

Renewable Power Energy System: This system is linked to the cloud through the home gateway. The solar panel converts sunlight, and the wind turbine converts wind energy into electricity. This electricity is stored in a battery connected to all devices. The end user can monitor the percentage of power.

Water Level in Water Tank System: A water level sensor activates a motor that pumps water into the tank in an efficient way. As seen both developed systems have been worked efficiently. However, regarding start time speed we have seen the MCU always starts first by few seconds before IoT.

CONCLUSION

The present study suggested a novel approach to lower the amount of water used for soil irrigation, i.e., preserve water and manage water resources as well, which has the potential to effectively increase agricultural sustainability and ensure food security. In fact, the study embraces the concept of ‘Smart Agricultural’ and the integration of advancing agricultural technologies. In light of the foregoing, the study introduced a ‘Smart Irrigation System’ that was developed by the researchers. Genuinely, the proposed system is built on embedded cutting-edge technologies; including the ‘Internet of Things’ (IoT) and the ‘Micro-Controller Unit’ (MCU). It is worth mentioning that the working mechanism of the aforesaid developed system, which operates automatically through the embedded MCU or remotely via IoT, is based on the idea that the sprinklers activate when the water level falls below (5) cm meanwhile is cut off when it surpasses (25.0) cm. additionally, the developed system can determine and approve whether the networked devices, IoT components, and MCU can function properly. In conclusion, our research has effectively proven the establishment of a smart irrigation system using IoT technology. The technology is made to use less water, give corps the best irrigation possible, and enable remote operation and monitoring. Several sensors are used in the data collecting stage to get information on the water level. After processing this data, the system moves on to the control stage, where it makes the required adjustments, such as turning on and off pumps, to guarantee ideal irrigation. The user can monitor and control the machine remotely thanks to the remote operation stage. The system's ability to reduce water consumption and provide corps with adequate watering is demonstrated by the trial results. Because of the system's ability to use less water, irrigation will cost less overall. All things considered; the research's smart irrigation system has the ability to completely change how agriculture uses irrigation. The technology is economical and effective, saving water and enabling the best possible irrigation. Furthermore, the system may be conveniently and easily monitored and controlled thanks to the remote operation capability. Farmers, landscapers, and other industries that depend on irrigation stand to gain a great deal from this technology, which might ultimately lead to a more maintainable and effective usage of water resources.

Duality of interest: There is no conflict of interest.

Author contributions: A.B The authors developed the theoretical work, implemented the system, tested it, and followed the system rules to obtain the findings from simulations. C author performed the writing and structure of the manuscript.

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