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Design of an IoT-based management and monitoring system for intelligent irrigation

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***Abstract*—** Agriculture plays a major role in the world economy and most people depend on it for their livelihood. This makes water an important resource that must be conserved using the latest available technologies. Today, the Internet of Things has expanded its capabilities to smart agriculture. In this research, an automated and low-cost system for intelligent irrigation based on a fuzzy-based energy-aware routing approach is presented. In addition, a neural network is trained to determine the best irrigation program, based on information received from sensors (such as temperature, soil moisture, etc.). The user in the system can monitor the data collection process with mobile phones, mobile computers, etc. and manage the irrigation of agricultural products. The proposed system proves its intelligence, low cost and portability, its suitability for greenhouses, farms, etc. The simulation results show that the proposed method offers better results compared to the LEACH protocol as well as the WSN-IoT algorithm in various criteria such as grid life and power consumption.

***Keywords*—**Internet of Things, Intelligent Irrigation, Intelligent Agriculture, Monitoring, LEACH Protocol.

I. INTRODUCTION

Agriculture plays an important role in many countries and needs to become an intelligent industry [1]. The agricultural industry is currently evolving using modern intelligent technologies to find solutions for efficient use of resources. This has made water an important resource that must be conserved using the latest available technologies. The non-industrial Internet of Things (IoT) has also developed its ability in intelligent agriculture [2]. Today, IoT is recognized as a new form of Internet use among users [2]. In IoT technology, all objects have a unique Internet address that can connect to the Internet. This new generation of the Internet has many applications in various fields, one of which is agriculture and irrigation of irrigated lands [3].

Modern and intelligent agriculture will be achieved by using interconnected communication equipment as well as new technologies such as IoT. Smart farming has advantages such as high and advanced efficiency, optimized arable land, and high planning accuracy and so on. The use of existing technologies in intelligent agriculture has made it possible for farmers to be more profitable, the attractiveness of the agricultural industry has also increased, and such tools will be provided to the farmer to help them face the problems and challenges ahead in the future. Slow [4]. An intelligent irrigation device communicates with various sensors and manages irrigation based on the information it receives from the sensors. These sensors can inform the central device of information such as whether it is raining or not, and the ambient temperature, as well as the amount of soil moisture or the intensity of the wind. The advantage of this system over timer irrigation controls is its impact on water consumption. Because irrigation is done only when your trees and plants need water [5].

With the advent of the Internet of Things and digital transformation in rural areas, remote control of irrigation, soil moisture, and crop growth monitoring as well as preventive measures to detect damage can be smartened. The use of this technology allows access to smart agriculture [5]. Remote management of agricultural activities with new technologies is a new field for research activities. This paper configures a fast and cost-effective management system for intelligent irrigation via wireless sensors and the Internet of Things. The data mining unit includes a set of wireless sensors to measure agricultural activities and collect information related to irrigation parameters [6]. Based on information received from sensors (such as temperature, soil moisture, etc.), a neural network is trained to determine the best irrigation program. The user in the system can connect to an Internet network with mobile phones, mobile computers, etc. and manage the process of collecting information through the Internet of Things and monitoring agricultural products. In addition, a fast fuzzy-based routing algorithm is designed to transmit information that helps distribute energy consumption across the network. The emphasis of the proposed method is on the analysis of the wireless sensor network node routing protocol (WSN) for sending information from the hardware system to the interface software such as a mobile application [3].

The rest of this article is as follows: Section II deals with background and motivation. Some of the most recent work done in Section III is reviewed. Section IV presents the proposed IoT-based method for creating an intelligent irrigation system. The results of the evaluation of the proposed method are given in Section V and finally the conclusions and suggestions are expressed in Section VI.

II. BACKGROUND AND MOTIVATION

Computers, and therefore the Internet, are almost entirely dependent on humans for information. This concept is at the core of intelligent technology and can be used to properly manage irrigation in gardens, greenhouses, farms and farmland. Smart farming is a well-established domain, and combining technology with farmers' experience has numerous benefits: including improved crop health, better hygiene, faster tracking, water management, and more. Water is one of the most important resources in agriculture [7]. Large amounts of water are used almost 100 times more than personal consumption in agriculture, and approximately 70% of river and groundwater is used for irrigation, which has made man the largest consumer of water resources [8]. In addition, almost half of the water in traditional agriculture is lost due to evaporation. This has led to extensive work on the efficient use of this limited resource. Much work has been done and is being done by various research groups in the field of smart agriculture. As most IoT technology suggests wireless sensor networks to manage water consumption.

III. RELATED WORKS

Much research has been done on the Internet of Things and irrigation intelligence in agriculture to increase the quality of agricultural production as well as save water. Krishnan et al. (2020) proposed fuzzy logic based on intelligent irrigation system using IoT [9]. In this paper, the fuzzy logic controller is used to calculate the input parameters (eg soil moisture, temperature and humidity) and generate the output of the engine condition. Karar et al. (2020) proposed IoT and neural network-based water pumping control system for intelligent irrigation [10]. This paper aims to save water consumption wasted in the process of irrigation using the Internet of Things based on a set of sensors and a multilayer perceptron neural network (MLP). Machine learning algorithms such as MLP neural network play an important role in supporting the decision of automatic control of IoT-based irrigation system, effectively managing water consumption.

Tiglao et al. (2020) proposed an intelligent irrigation system based on low-cost wireless network called Agrinex [11]. This provides an alternative to existing agricultural land monitoring methods while providing an irrigation mechanism to assist resource conservation measures using a wireless sensor and excitation network. The Agrinex system has a network-like configuration of in-field nodes that acts both as a sensor for soil moisture, temperature and humidity, and as an actuator on a valve that regulates drip irrigation. Mousavi et al. (2020) proposed an approach to improve IoT security using cryptographic algorithms for intelligent irrigation systems [12]. This paper proposes a new hybrid encryption algorithm based on hedge encryption, elliptic-curve encryption, and secure hash algorithm to protect sensitive information in IoT-based intelligent irrigation systems. The results confirm the effectiveness of this model and the robustness for confidentiality based on confidentiality analysis.

The WSN-IoT algorithm was proposed by Nawandar and Satpute (2019), which is a low-cost and intelligent IoT-based module for creating an intelligent irrigation system [13]. Features of this software include admin mode to interact with the user, make settings only once for irrigation program estimation, neural network-based decision making for intelligent support and remote data monitoring. In addition, the system uses MQTT and HTTP to inform the user about the current status of crops and irrigation conditions even from a remote location. Alomar and Alazzam (2018) proposed an intelligent irrigation system using IoT controller and fuzzy logic [14]. The purpose of this paper is to provide an IoT-based irrigation system that helps reduce irrigation frequency while increasing production through the use of fuzzy logic. The system consists of a Mamdani fuzzy controller that obtains environmental indicators such as soil moisture and outside temperature through special sensors, then applies a series of fuzzy rules to control the flow of water through the water pump, and provides the right time and frequency for irrigation.

IV. THE PROPOSED METHOD

This paper presents an intelligent crop monitoring and irrigation system based on fuzzy logic and neural network. Taking into account the needs of plants and soil, the proposed intelligent irrigation system achieves efficient utilization of water. To do this, the parameters of plant growth stage, ambient temperature, ambient humidity, soil moisture, evaporation rate, crop growth rate, crop water requirement, crop planting time, maximum and minimum temperature, geographical location, rainfall, irrigation method and type of mechanical stimulus Note that is received from WSN. These parameters generally determine the water requirement of a product, which can be used to develop an intelligent and automatic irrigation system without any human intervention. In the proposed intelligent irrigation system, continuous monitoring of the environment, reading sensor data, connecting to a broker to disseminate information, deciding on irrigation mode, deciding on the amount of water output, transferring the decision to the Irrigation Unit (IU), decision feedback it is done from the irrigation unit. Fig. 1 shows a conceptual architecture of the proposed method consisting of four layers.

The first layer is related to data collection through a WSN with a fixed number of nodes. The nodes used in this section have the ability to collect the parameters defined for irrigation through a sense of environment. These nodes are capable of converting analog to digital signals and use the radio frequency protocol to transmit information. In addition to WSN-related equipment, a water source is available here via the IU that can enforce submitted decisions. The second layer consists of a Sensor Information Unit (SIU), which is responsible for processing data and communicating with devices connected to the Internet. Also, SIU can communicate and exchange data. The third layer consists of a GSM modem connected to the Internet through which the SIU can send information received from the WSN to the server (or application). Therefore, data analysis is performed by the server, which simplifies the system architecture. The fourth layer consists of a server or an application platform whose user (farmer) can view and manage its data. An application can be an app or website that runs on a mobile phone or personal computer.

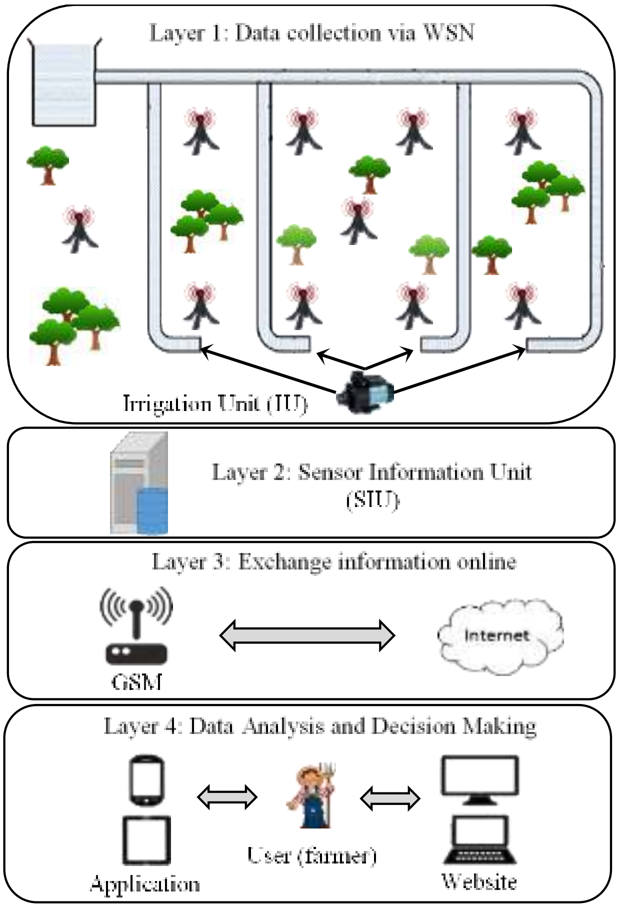

Figure 1. Proposed irrigation system architecture

In this paper, a fast and low cost management system has been designed for intelligent irrigation through IoT. A number of wireless sensors are used to collect data. These sensors provide information such as temperature, soil moisture, temperature, amount of light, measurement of frost, and so on. This data is used to measure agricultural activities and better manage the irrigation system. Based on the collected information, a neural network is trained to determine the best irrigation program. Here, a series of real inputs-outputs are used to train the neural network, which will be provided by an expert. The user in the system can connect to an Internet network with mobile phones, mobile computers, etc. and manage the process of collecting information through the Internet of Things and monitoring agricultural products. In addition, a fast fuzzy-based routing algorithm is designed to transmit information. The proposed routing algorithm creates a routing table for all sensors at the beginning of the setup, and the routing table is updated only if one sensor (neighborhood switch) is deactivated.

The basic routing protocol for implementing the proposed irrigation system is OSPF. In this protocol, SPF algorithm is used for routing and is based only on bandwidth [15]. In this paper the routing process in the OSPF protocol is improved by a fuzzy system. Here, the network topology specifications are considered as input based on a set of standard parameters.

The target network is a WSN network and includes a set of sensor nodes with the ability to send data. These nodes are actually IoT operators. Initially, the OSPF protocol is based on WSN. This is done by sending a "hello" message and creating a neighborhood table. The communication status between the sensor nodes is then determined by sending an LSA message, and the network neighborhood table is created accordingly. Each node that receives the LSA message updates its neighborhood table and sends an LSA message to other neighboring nodes. Neighborhood is defined here based on a threshold distance. In the next step, a routing table is created for each node. This is done by developing the SPF algorithm with a fuzzy approach for each node. The OSPF protocol alternately modifies the neighborhood table based on LSA messages. However, LSA is sent only in two cases: 1- Changes in the status of the links (for example, the end of the energy of a node) and 2- A specified time range (for example, every t-second). Therefore, in the event of a change, each node will update its neighborhood table and notify its neighbors by sending an LSA.

A. Fuzzy approach to creating a routing table

The proposed routing system is such that the source node is first considered as the current node of the path $(node_c)$. Then, based on $node_c$, all candidate nodes of the next node are specified. That is, $Candid(node_c) = \{node_1, node_2, \dots, node_{z1}\}$. Where $z1$ indicates the number of candidate nodes for the current node $node_c$. Here, neighboring nodes are considered as candidate nodes. Next, based on a law-based fuzzy system, for each node of the set of candidate nodes, the effect of its selection is calculated. Then one node is selected from the candidate nodes as the next node of the path, this selection is done based on the impact factor and the roulette wheel technique. Assuming the node $node_1$ is selected, this node is considered as the current node, i.e., $node_c = node_1$. This process is repeated for the current node until the destination node is selected.

The fuzzy system is designed based on the parameters "residual energy of the candidate node", "distance of the candidate node from the current node", "distance of the candidate node from the SIU" and "link bandwidth between the current node and the candidate node" determines the impact of each candidate node Slowly Here the input parameters include 1- energy (ER), 2- distance (DS) and 3- bandwidth (BW) (parameters of candidate node distance from current node and candidate node distance from SIU are considered as average sound Has been). First, the values of these parameters are normalized based on the maximum value and then they are fuzzy based on the fuzzy set of trapezoids with three modes (Low, Middle and High). Fig. 3 shows the fuzzy set of the considered trapezoid. The output of the fuzzy system is also the impact factor, which is modeled by the trapezoidal fuzzy set.

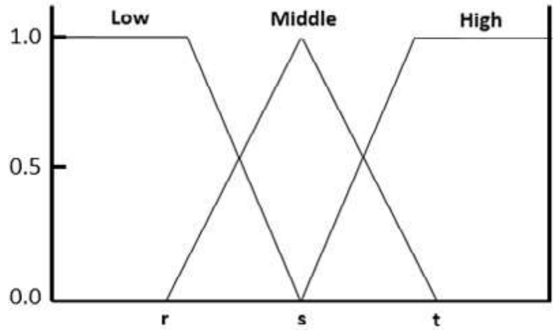

Figure 2. Fuzzification of input parameters

The output is determined by a fuzzy rule database designed by an expert, where the degree of membership of each input pattern is calculated using the multiplier. The fuzzy rules considered are shown in Table I.

Table 1. Database of fuzzy rules used in routing algorithms

Rule number	System input			System output
	Energy	Distance	Bandwidth	Impact factor
1	Low	Low	Low v Mid	Low
2	Low	Low	High	Mid
3	Low	High v Mid	Low v Mid v High	Low
4	Mid v High	Low	Low	Mid
5	Mid	Low	Mid v High	High
6	Mid	Mid	Low v Mid	Mid
7	Mid v High	High	Low v Mid	Low
8	Mid	High	High	Mid
9	High	Low	Mid v High	High
10	High	Mid	Low v Mid	Mid
11	High v Mid	Mid v High	High	High
12	High	High	Mid	Mid

B. *Select the best irrigation program by neural network*

Most research uses a threshold to decide on the type of irrigation. For example, if the temperature drops below -5, there is a possibility of freezing and irrigation. However, the parameters under consideration often include ambient temperature, humidity, soil-water content, which do not provide a simple relationship for decision making. Therefore, in this paper, an attempt has been made to use the neural network model instead of the threshold, where it can make the best decision for the current situation based on past conditions. Here, a neural network is trained to determine the best irrigation program based on information gathered by the IoT. To do this, a series of real inputs-outputs are used to train the neural network, this information is provided by an expert. The inputs considered in this system include ambient temperature, ambient humidity, soil moisture, evaporation rate, crop growth rate, crop water requirement, crop planting time and rainfall. In addition, the output of the system is a type of irrigation program that includes low pressure drip irrigation, high pressure drip irrigation, low pressure sprinkler irrigation, high pressure sprinkler irrigation, low pressure surface irrigation and shallow pressure irrigation Is high.

In this paper, a multilayer perceptron neural network (MLP-NNs) is used, which has three input, hidden and output layers. The input characteristics according to the parameters extracted by the sensors are equal to I_n and the number of outputs according to the defined irrigation types is equal to O_n. In addition, the number of hidden layers is 1 and the number of neurons in this layer is 4. The number of learning courses is equal to 1000 and the technique of learning weights is defined. The output of each node is generated by calculating the weight value of its input values and then performing the sigmoid activation function. Finally, the mean square error (MSE) of the output is calculated based on its difference from the actual sample output. Fig. 3 shows an example of an MLP-NN architecture based on a 3–4–1 configuration (i.e., 3 input nodes, 4 nodes in a hidden layer, and 1 output node).

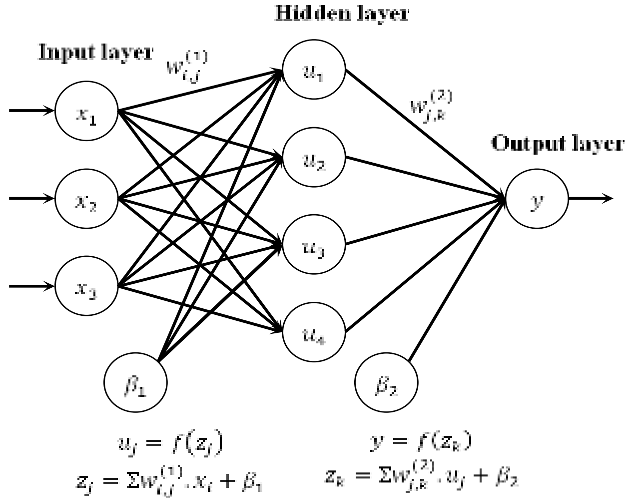

Figure 3. An example of the structure of the MLP neural network used

V. RESULTS AND DISCUSSION

The simulation is performed with MATLAB software version 2019a and all tests are performed by an Asus laptop with Intel core i7 processor and frequency and 3.0 GHz, 16GB memory. The simulation is performed on an IoT-based wireless sensor network topology. In the experiments performed, the values set for the parameters of the proposed method are as follows; Number of simulation cycles equal to 5000, LSA transmission time range equal to 5 simulation cycles, agricultural land size equal to 100×100 meters, number of sensor nodes equal to 100, position of sensor nodes randomly with uniform distribution, initial energy Nodes are 0.2 joules, information packet size is 4 KB, hello packet size is 25 bits, sensor unit information position is 50×50 meters and number of fuzzy rules is 12.

The energy consumption model according to [13] is used to send and receive data. In this model, if the distance between two nodes is greater than the threshold distance d_0, the nodes send the packet with the maximum power level, otherwise it is sent based on the distance with a medium power level. In this model, the energy consumption for the sending nodes (E_{tx}) and the receiving nodes (E_{rx}) is measured according to Eq. (1) and Eq. (2).

$$E_{tx}(d) = \begin{cases} E_{elec} \times l + \varepsilon_{fs} \times l \times d^2 \quad , & d < d_0 \\ E_{elec} \times l + \varepsilon_{mp} \times l \times d^4 \, , & d \geq d_0 \end{cases} \tag{1}$$

$$E_{rx} = E_{elec} * l \tag{2}$$

Where, E_{elec} is the energy needed to send/receive a bit. l and d are the packet size and the distance between the sender and receiver nodes, respectively. ε_{fs} and ε_{mp} are amplifier energies for signal amplification. In most studies, the d_0 threshold is considered as Eq. (3).

$$d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}} \tag{3}$$

Based on the information collected by the Internet of Things, a neural network has been trained to determine the best irrigation program. The details of the neural network configuration are as shown in Table II.

Table 2 Details of neural network configuration to determine irrigation schedule

parameters	Values
Inputs	7 inputs including ambient temperature, ambient humidity, soil moisture, evaporation rate, crop growth rate, crop water requirement, crop planting time and rainfall
Hidden layer configuration	1 hidden layer with 4 neurons
Number of learning epochs	1000 epochs
Learning algorithm	Gradient Descent
Outputs	6 outputs include low pressure drip irrigation, high pressure drip irrigation, low pressure sprinkler irrigation, high pressure sprinkler irrigation, low pressure surface irrigation and high pressure surface irrigation
Number of training records	500 records
How to create records	Random with uniform distribution, in the range 0 to 1 for each feature

In this section, extensive experiments have been performed to evaluate the performance of the proposed algorithm. First, the study of neural network convergence with 100 periods is presented. The neural network learning outcomes can be seen in Fig. 4, where the error is measured based on the square mean error (MSE). In the validation process, the best performance was achieved in period 85 with MSE equal to 0.0037699.

In the following, the residual energy of the network in the proposed method is compared to the routing cycles against the LEACH protocol [16] and the WSN-IoT algorithm [13]. At each routing cycle, the residual energy of the network is equal to the average residual energy for all network nodes. The results of this comparison are presented in Fig. 5. In the first round of simulation, the grid energy is 20 joules. Here, a decreasing trend of grid energy is observed during routing cycles for all methods. However, the proposed method shows less acceleration in energy reduction than other methods. The reason for the superiority of the proposed method is the use of energy-aware technique in routing as well as proper distribution of energy consumption.

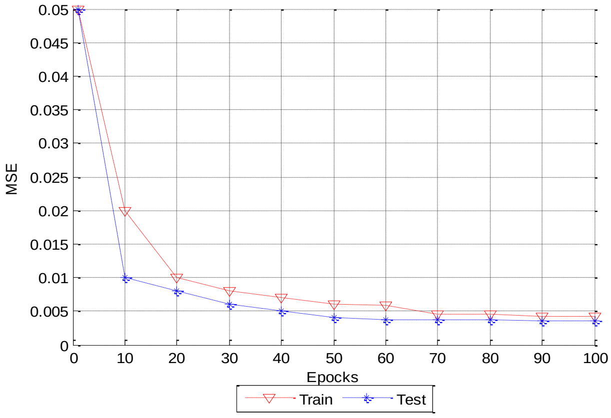

Figure 4. Neural network convergence results

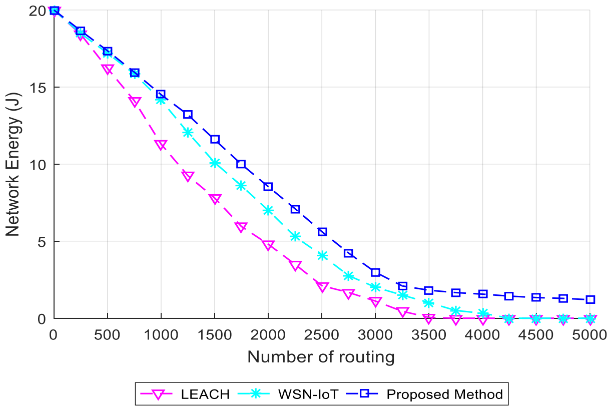

Figure 5. Comparison of network residual energy in different methods

In another experiment, network lifetime and number of live nodes were compared based on routing cycles in different methods. Fig. 6 shows the results of this comparison.

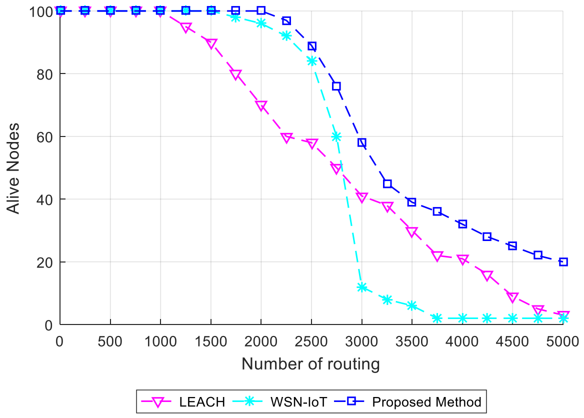

Figure 6. Compare the number of live nodes in different methods

In the proposed method, death is the first node of the 2109 routing. This criterion is 1057 for the LEACH protocol and 1625 for the WSN-IoT algorithm. Therefore, the proposed method offers better network life. In addition, after completing 5000 routing rounds, the proposed method with 22 live nodes reports better results than the LEACH protocol with 2 and the WSN-IoT algorithm with 4 live nodes.

VI. CONCLUSIONS AND SUGGESTIONS

The world's population is growing and the current food supply is not enough to feed people. Today, traditional agriculture can be one of the reasons for the decline in food production, even if a lot of arable land is available. Therefore, it is necessary to integrate developing technologies with agriculture and perform intelligent agriculture. In addition, agriculture plays a major role in the world economy and most people depend on it for their livelihood. This makes water an important resource that must be conserved using the latest available technologies. Today, the Internet of Things has expanded its capabilities to smart agriculture. In this paper, an automated and low-cost system for intelligent irrigation was designed. Here, the Internet of Things is used to build devices that automatically communicate with each other in the system and have features such as: manager mode for user interaction, setting irrigation schedule, network-based decision making Nervous for intelligent support and remote monitoring of data. The proposed system has proven to be intelligent, low cost and portable, suitable for greenhouses, farms, etc.

For future work, it is recommended to use an IoT-enabled microcontroller to transfer information between the sensor nodes and the node processing unit, and to speed up the data transfer process. In addition, the use and comparison of the performance of the OSPF protocol against other new protocols such as EIGRP [17] is another suggestion of this research.

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