

Smart irrigation based on cutting-edge technologies

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Abstract

The Tunisian economy's main driver is agriculture. A significant amount of the freshwater used in this industry is for irrigation. By missing the timings throughout this irrigation procedure, people waste more water. A drop in output rates has been caused by the improper management of irrigation water. Therefore, developing intelligent methods and systems based on cutting-edge technology is essential for the efficient use of fresh water, especially in dry regions with a scarcity of rainfall. Smart irrigation systems might be a viable way to avoid both over- and under-irrigation while also playing a significant part in reducing water use. Thus, we will suggest in this study a novel approach for smart irrigation in the southern Tunisia region to optimize water use and give a remote control and monitoring for the irrigation system. For this, a cloud-based wireless communication system was proposed and evaluated to monitor and control a set of sensors (soil moisture, flowmeter, solenoid valve, water level, and weather temperature) and actuators to assess the plant water need.

Keywords

Smart irrigation, IoT, wireless sensor network, cloud computing

1. Introduction

In Tunisia, particularly in the southern area, agriculture is a crucial and essential industry for economic growth. There are large agricultural surfaces and sunlight in this semi-arid and Saharan region, which provide all the conditions needed for agriculture. Notably, 10% of the nation's GDP and 15% of jobs are generated by the agricultural sector [1]. In comparison to other industries, agriculture and animal production consume the most fresh water globally. In actuality, 70% of the freshwater that is extracted globally is used for agricultural purposes [2]. Due to population increase and rising food demand, this ratio will continue to dominate water usage. One of the agricultural practices that uses the most water globally is irrigation, and its use has been rising over time. Low irrigation efficiency, however, is one of the main causes of water waste. According to the UN Food and Agriculture Organization (FAO), 60% of the

water diverted or pumped for irrigation is now lost to evapotranspiration or runoff into rivers [3]. This has led to a significant increase in the demand for intelligent irrigation systems that can deliver efficiency that is impossible to achieve without sufficient data analysis and suitable implementation strategies. Therefore, the intelligent irrigation techniques should be implemented in a way that uses less water than previous ones. In fact, water waste may be reduced by up to 95% with smart irrigation techniques, compared to 20%–70% using traditional methods [4]. Smart irrigation is a growing field of science that uses data-intensive techniques to boost agricultural output while lowering its environmental effect. Modern agricultural operations gather data from a range of sensors, improving the understanding of both the operation environment and the operation's activities [5]. To maximize cost effectiveness for the farmer, smart irrigation aims to utilize Internet of Things (IoT) and analytical approaches to leverage precision irrigation.

This is done by flowing the water in the right amount to the right places at the right times. These IoT-based smart irrigation systems rely heavily on automatic signals that are triggered by data. Sensors and actuators produce and receive these signals, which are then controlled through wired and wireless interfaces such as IEEE 802.15.4 and IEEE 802.11 [6].

IoT is a broad term describing the capacity of network devices to sense and gather information about the environment around us, and then transmit that information via the Internet so that it may be analyzed and used for a variety of intriguing reasons. Other technologies focus on improving current services or offering goods that are simple to use and ergonomic, while IoT places the highest priority on optimization, with optimization techniques being essential to the success of any of its systems [7].

IoT technology is also applied in various fields, such as agricultural production activity. Using the IoT, farmers obtain information on all agricultural activities. Agricultural processes are monitored by various technologies connected via the Internet, such as sensors, smart cameras, mobile applications, and devices (mini chips), through the collection of various information from sensors, such as crop growth, fertility soil, temperature, rainfall, and seed planting information. Infrequently, automated technology aids farmers in determining the greatest use for their limited resources and resolving issues with their farming practices, such as when to sow their crops and when to harvest them [8].

Many studies try and strive to develop and improve the functions of the IoT. Benhmad et al. [9] described the creation of a wireless sensor network (WSN), which has developed into a vital instrument for environmental monitoring. The devices' generally low cost enables the installation of a dense population of nodes that can accurately represent the environmental variations [10].

The development of WSN applications in precision agriculture can increase the efficiency, productivity, and profitability of many agricultural production systems, while minimizing unintended impacts on wildlife and the environment. The real-time information obtained from the fields can provide a solid basis for farmers to adjust their strategies at any time [11].

We ensure that the importance of water has become an expensive and valuable resource due to its increasing supply around the world. Farmers and agronomists face challenges in reducing water consumption and establishing the best irrigation schedules. They created a website-based monitoring system for decision support that collaborates with a

WSN to plan irrigation, aids the farmer in reorganizing the farms using maps from a geographic information system, and delivers the essential data, including measurements of the soil and climate. The design, analysis, and implementation of this system are presented to adapt the design changes to the location of fields, crops, and irrigation patterns, taking into account all the particularities of the constraints of the environments such as device availability, field conditions, etc. [12].

Every day, the writers work to make better use of water while gathering fundamental information for studies on the many types of water penetration in the soil. Chen et al. [13] presented a method for employing a WSN to monitor the temperature and moisture of many layers of soil in an agricultural field.

Qi [14] presented an environmental greenhouse monitoring system to address issues with the existing greenhouse monitoring system, including difficult cabling, high energy consumption, a finite transmission range, and rigid deployment. For the administration of sensor nodes, data processing, and early warning of weather disasters, a gateway management system was designed on an embedded database.

Much research has been carried out to improve the performance of the agricultural sector. In Putjaika et al. [15], the system uses sensors and a microcontroller (an Arduino) to control the irrigation and the roof of an openair farm. For decision making, it compares statistical data obtained from sensor systems (such as humidity, temperature, and light intensity sensors) with weather forecasts. The detected data would not always be precise because of the noise. The sensors' noise is reduced using the Kalman filter [16,17]. The authors also developed a smart solar-powered monitoring and irrigation process. The use of solar panels with a tracking system based on light-dependent resistor (LDR) for the purpose of powering smart irrigation controlled by the microcontroller (Arduino) has been seen in smart irrigation systems based on renewable energy [18]. The system also addresses desert-specific challenges, such as dust, infertile sandy soils, constant wind, very low humidity, and extreme variations in daytime and seasonal temperatures.

Veermanikandasamy et al. [19] presented an automated system combining ZigBee and GSM technologies to efficiently utilize water resources for farming and agricultural growth monitoring. Even with drip irrigation, the effective application of irrigation and fertilizer is crucial for maximizing agricultural water output and water losses [20]. In Gutiérrez and Villa-Medina [21], optimization of water use for agricultural crops is the result

of the development of automatic irrigation systems. It has a distributed wireless network of soil moisture and temperature sensors. In addition, the accumulated information comes from sensors that locate and distribute it to various areas to be managed by a gateway unit and transmits the data to a web application. With temperature and soil humidity threshold values that have been programmed into a gateway based on a microcontroller, it will be possible to control the amount of water. In addition, the system was powered by solar panels. In John et al. [22], the article explains the WSN used to detect soil moisture level, temperature, and relative humidity values. The lifetime of the network of nodes is increased by using a sleep-wake plan. The system described in this article implements node clustering. For data management, the author uses MATLAB (MathWorks, Natick, Massachusetts, USA) software as a graphical user interface [23]. Remote farming automation involves sensors and actuators that are linked to an IoT server. Benefits of cloud services (process controller installation or setup) include the ability to adjust control rules practically without having to update the firmware of distant sensors or actuators [24]. WSNs are widely used for monitoring environmental conditions such as pressure, sound, temperature, home monitoring, and disaster relief. Sensors must provide accurate and timely information in health and military applications. The large storage and compute needs of intelligent applications are met by the cloud computing paradigm. Energy integration of WSNs with the cloud helps develop low-cost compute and storage applications.

To accomplish system performance and data storage, this article provides an irrigation system that illustrates the fusion of a WSN, IoT communication technology, and a cloud server. With real-time sensing of atmospheric and soil parameters such as air temperature, humidity, and soil moisture, the suggested system enables remote monitoring and control of irrigation. IoT-based irrigation raises agricultural output without requiring human intervention.

The climate of southern Tunisia and more precisely the so-called Nefzawa area is characterized by very high heat and drought due to the lack of precipitation and the scarcity of rain all year round, and therefore, the serious shortage of water. In light of these developments in novel technology, the Internet, and the IoT, we proposed in this article, a plan for smart irrigation in the region of southern Tunisia based on the use of the IoT and contemporary communication technologies. To implement our smart irrigation system in the southern region of Tunisia, we followed a multistep field methodology. First, we conducted a

thorough assessment of the water requirements of the dominant agricultural crops in the region, taking into account the different water requirements at different growth stages. Next, we installed high-precision sensors, such as soil moisture sensors, weather sensors, and flow meters, as well as actuators such as solenoid valves, in the selected agricultural areas. These sensors and actuators enabled the continuous collection of data in the field, such as soil moisture, rainfall, temperature, and water flow. The collected data were then analyzed in real time using advanced analysis algorithms to assess crop water needs and determine optimal times for irrigation. Based on this analysis, we adjusted the irrigation parameters in real time, controlling the solenoid valves if there is a water leak to provide the necessary amount of water at the right time and in the right place. So, our study addresses a critical gap in current literature by introducing an innovative approach to water management in agricultural settings, with a specific focus on pomegranate and date palm plantations. Through the implementation of a comprehensive IoT framework and the analysis of real-time data collected over an extended period, combined with the application of sophisticated algorithms for irrigation scheduling and optimization, we provided valuable insights into maximizing crop yield while minimizing water consumption. This research contributes significantly to the field by offering practical solutions to address the pressing challenges of water scarcity in agricultural regions, thereby presenting a fresh perspective on sustainable farming practices. Finally, we provided training to local farmers on the use and maintenance of the smart irrigation system, as well as the benefits of efficient water management. The structure of this paper is as follows: the study is divided into five sections: Section 2 offers a recommended diagnostic method, Section 3 presents the agricultural analyses of data, Section 4 contains the findings and discussion, and Section 5 concludes the essay.

II. Methods

a. Modelling

Any problem being researched must be accurately characterized. The role-modeling process is now complete. The analyst recommends a description method in which he accounts for numerous influent factors that are thought to create differences in the outcomes. This research, which examines a farm's water allocation methodology, will emphasize that point. In actuality, one works with a procedure

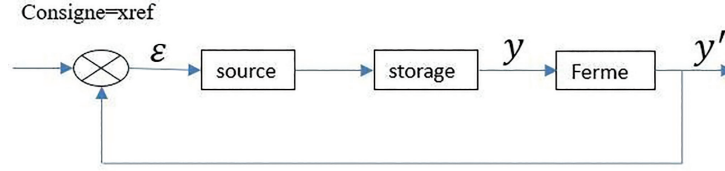


Figure 1: Spam traffic sample.

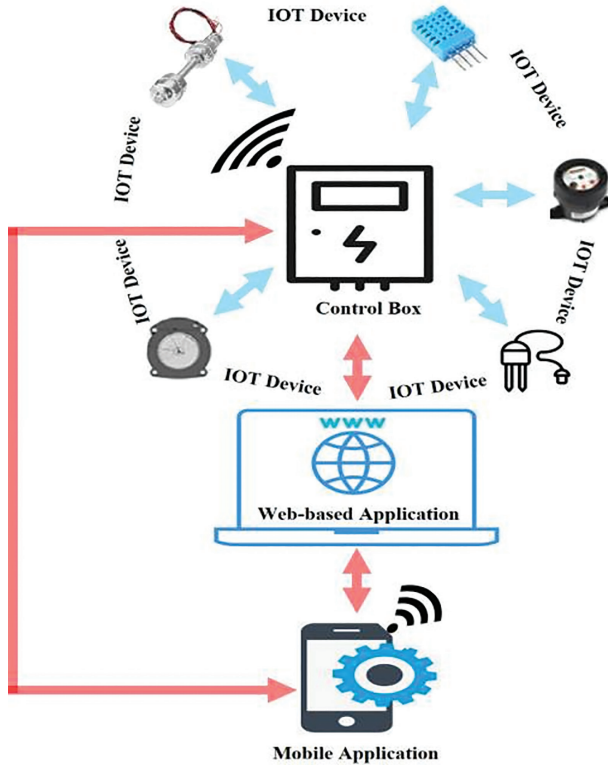


Figure 2: An overview of the system.
IoT, Internet of Things.

that, when referred to in terms of the general control scheme, may be recalled as Follows, Figure 1.

b. WAM model

An agricultural optimization model is Watershed Assessment Model (WAM). It makes use of information on the amount of land that is available, the amount of water that various crops require per square foot of land, and the net profits such crops earn per square foot of land [25].

- Applying WAM to real data reveals that the model roughly approximates how farmers actually react to water costs.
- Planners can use WAM data as a rough estimate.

- Planners may be alerted that more research is necessary if real behavior deviates from the WAM-generated optima.
- To evaluate uncertainty, plan stability, and risk, WAM offers a quantitative post-optimal numerical simulation.
- The use of WAM as a decision-support tool can help planners by advising them on the crop patterns that are most likely to succeed in a given set of circumstances and connecting them to various water management strategies.

At the level of several provinces, the WAM is developed. The goal of this function may be characterized as the maximization of net farm revenue through the choice of the best possible arrangement of water-using activities. Constraints in WAM entail the use of both land and water. The user has the option to set restrictions on the water's seasonal, quality-based, and class-level-representative availability as well as soil quality. This interest is sparked in part by WAM's capacity to provide data on particular crops or groups and in part by the reality that pricing and water regulations are not the only factors influencing crop selection and water use [25].

c. WAM represented mathematically

A variety of elements are considered in the proper management of this resource. To properly analyze an optimization problem, an objective function must be defined. The selected model can be provided in with regard to such restrictions in Eq. (1) as follows [26]:

$$\begin{aligned} \text{Max } Z = & \sum_j \sum_s \sum_m \sum_g x_{jsmg} \\ & \times \left[\text{wrc}_{jsmg} = \sum_i \sum_m \sum_g (p_{img} w_{img}) - \sum_i \sum_m \sum_g w + (i-1)mg \right] \end{aligned} \quad (1)$$

- where (Z) denotes the highest total net agricultural revenue ever realized.
- x_{jsmg} represents the entire area of land used for activity j (fruit trees, vegetables, and field crops)

over the s (summer, autumn, spring, and winter) seasons while utilizing water supply m .

- wrc_{jsmg} refers the contribution to water resources made by activity j during season s while utilizing water source m in district area g .
- P_{img} represents the cost of water in district area g during month i from source m .
- w_{img} refers the amount of irrigation water supplied by source m , in region area g , in month i .
- $w_{(i-1)mg}^+$ is the volume of water from source m that is kept in district g in month i . The following limitations apply to this objective function:

$$\sum_j \sum_m a_{ijmg} x_{jmg} + \sum_i \sum_m \sum_g (-w_{img}^o - w_{i-1,mg}^+ + w_{i+1,mg}^-) \leq 0 \quad (2)$$

- where (a_{ijmg}) represents the amount of water needed by activity j in district area g for water quality m at month i .
- W_{img}^o represents the entire amount of water of quality m supplied during month i , excluding storage in area g .
- $W_{i-1,mg}^+$ represents the transfer of water in district g of quality m from the preceding month i .

- $W_{i+1,mg}^-$ refers the forwarding of water of grade m to the next month in the district g .

$$\sum_j \sum_s \sum_n \sum_g x_{jsng} \leq A_{sng} \quad (3)$$

A_{sng} refers the entire area allotted for crop category n during season s in district g where crop category includes field crops, fruit trees, and vegetables, and seasons are summer, autumn, spring, and winter.

d. Model management based on IoT technology

The former model could be widely adopted in different interesting applications. Based on that idea, this has been retained for a farm management. This targets best exploiting such conventional and widely encountered usage. The state technological art uses nowadays a novel and recent means having offered a wide world network named Internet. Such new network lives an extension toward things. Various sensors grouped in a specialized network named IoT are now requesting information (transmitting or receiving) Figure 3. That's what one can be observed in the

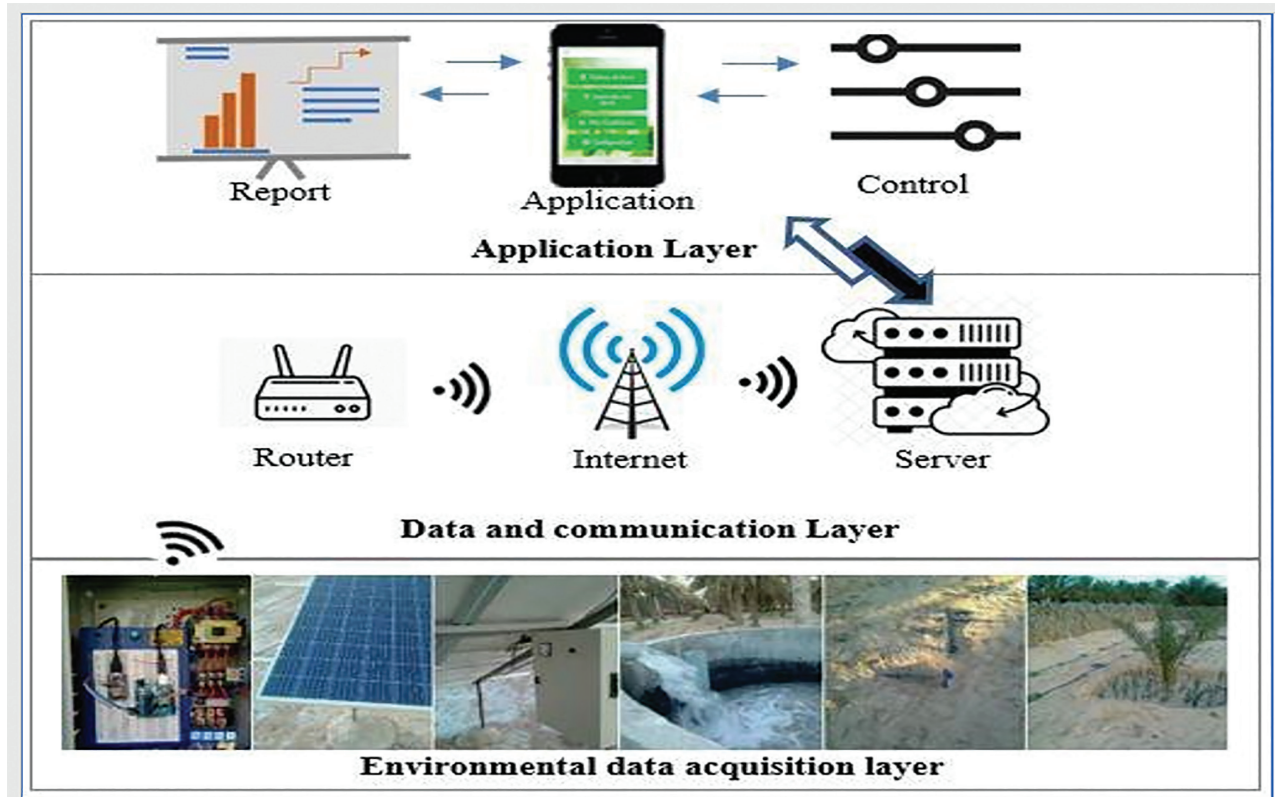


Figure 3: System control architecture.

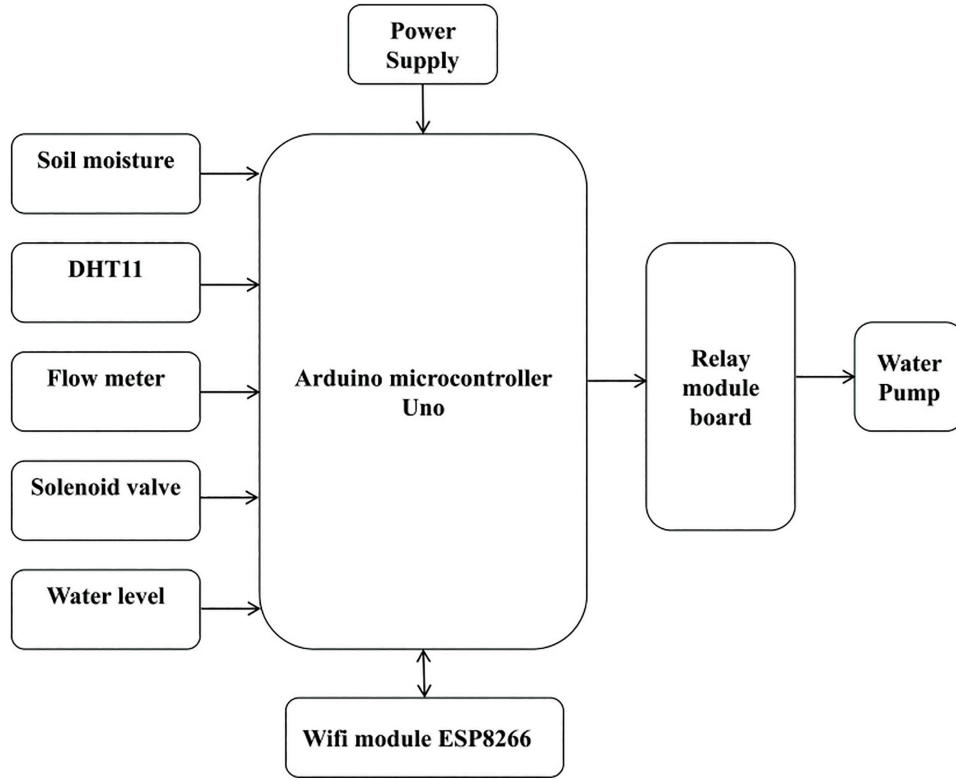


Figure 4: Block diagram of wireless sensor node.

following examples which show typical applications based on the block diagram Figure 4.

e. Studied system

This work is available for a variety of agricultural applications, including greenhouse, farm, garden, etc. An automated irrigation system will be able to monitor the crop's water requirements and notify the user. So, a farm for real-time data would be suggested.

A smart system assists in proper plant irrigation by taking into account the demands of the plant and soil. It also accomplishes optimal water usage. Using the information provided, we suggest the following algorithm, which uses the parameters listed below (see Table 1) [27].

A quick review of the literature might direct the instructor to a set of equations that represent the previously mentioned aims in order to address this need. In reality, to explain those demands, we have kept Eqs (4) and (5) as follows [27,28]:

$$W_c = \psi(P_g, A_t, A_h, S_m, ET_c) \quad (4)$$

$$ET_c(t) = IA \times \sum c(CI_c \times K_c \times ET_0(t)) \quad (5)$$

However, for palm plant type, we proposed Eqs (6) and (7) as indicated below [29,30]:

$$ET_m = ET_0 \times K_c \times S_a \quad (6)$$

$$S_a = R_a \times 2\pi \quad (7)$$

Based on former descriptions, one can summarize the proposed system over an algorithm scheme as illustrated in Figure 5.

We can also literally summarize algorithms (Algorithm 1 and Algorithm 2) over the following descriptions, which are more illustrated over the flow-chart given in Figure 6.

III. Case Study: Water Management in a Pomegranate and Date Palm Plantation (Nour Date)

In this study, we delve into the complexities of water management within our pomegranate and date palm plantation, with a specific focus on the Nour Date variety, situated in a region celebrated for its date production, in the southwestern part of Tunisia near

Table 1: Nomenclature used in the work.

Symbol	Definition
S_m	Soil moisture
t	Ambient temperature
h	Ambient humidity
F_m	Flow meter
P_{wl}	Pump water level
T_{wl}	Tank water level
ir_on	Start irrigation
ir_off	Stop irrigation
V_{ref_fm}	Flow meter reference value
p_{rv}	Water level reference value
t_{rv}	Tank level reference value
V_{ref_sm}	Soil moisture reference value
ET_0	Reference evapotranspiration
ET_c	Crop evapotranspiration
S_a	Area of evapotranspiration
R_a	Active radius
ET_m	Palm evapotranspiration
ψ	Function modeled using neural network
W_c	Crop water needs as a function of ψ
S_{v1}	Solenoid valve1
S_{v2}	Solenoid valve2
I_A	Area actually irrigated in percentage.
C	Irrigated crop
C_{lc}	Crop intensity
K_c	Crop coefficient
P_{pi}	Palm production income
P_{opi}	Pomegranate production income

Algorithm 1. Sensor response during irrigation

```

1: Inputs:  $trv$ ,  $prv$ 
2: Output:  $ir\_on$  or  $ir\_off$ 
3: for setup do
4:   Select  $\rightarrow pwl$  for  $prv$  &  $twl$  for  $trv$ 
5: end for
6: for ~setup do
7:   Read  $t$ ,  $h$ ,  $Sm$ ,  $Fm$ 
8:   Connect and send data using QTT
9:   Switch (expression [W])
10: {
11:   Case  $Sv1$ :....break
12:   Case  $Sv2$ :....break
13: }
14: end for
15: End

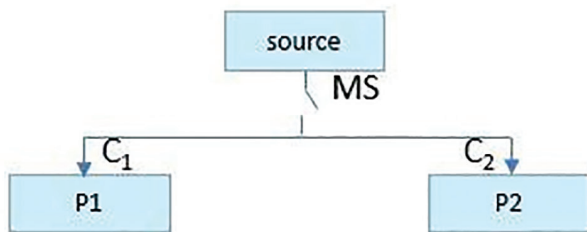
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Algorithm 2. General irrigation distribution Model

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1: Inputs: S
2: Output: P
3: for setup do
4:   for  $i = 1$  to 2 do
5:     while ( $Vref\_sm > S_m$  &  $T_{wl} > trv$  &  $Vref\_fm > F_m$ )
6:        $Svi \rightarrow Ci$ 
7:       Read( $Svi$ )
8:     end for
9:   end for
10: End

```

**Figure 5: Proposed algorithm scheme.**

the Sahara, the plantation grapples with a significant water scarcity challenge. Our research journey commenced with the deployment of a comprehensive

IoT framework tailored to monitor and control critical parameters essential for efficient water management. This framework incorporates a network of sensors strategically placed throughout the plantation to consistently assess soil moisture levels, climatic conditions, and water consumption patterns.

a. The real-situation test area

In this work and in order to check the utility of our framework, we have chosen to install it on an agricultural land that is really exploited. Two examples of subagricultural lands from a common land were

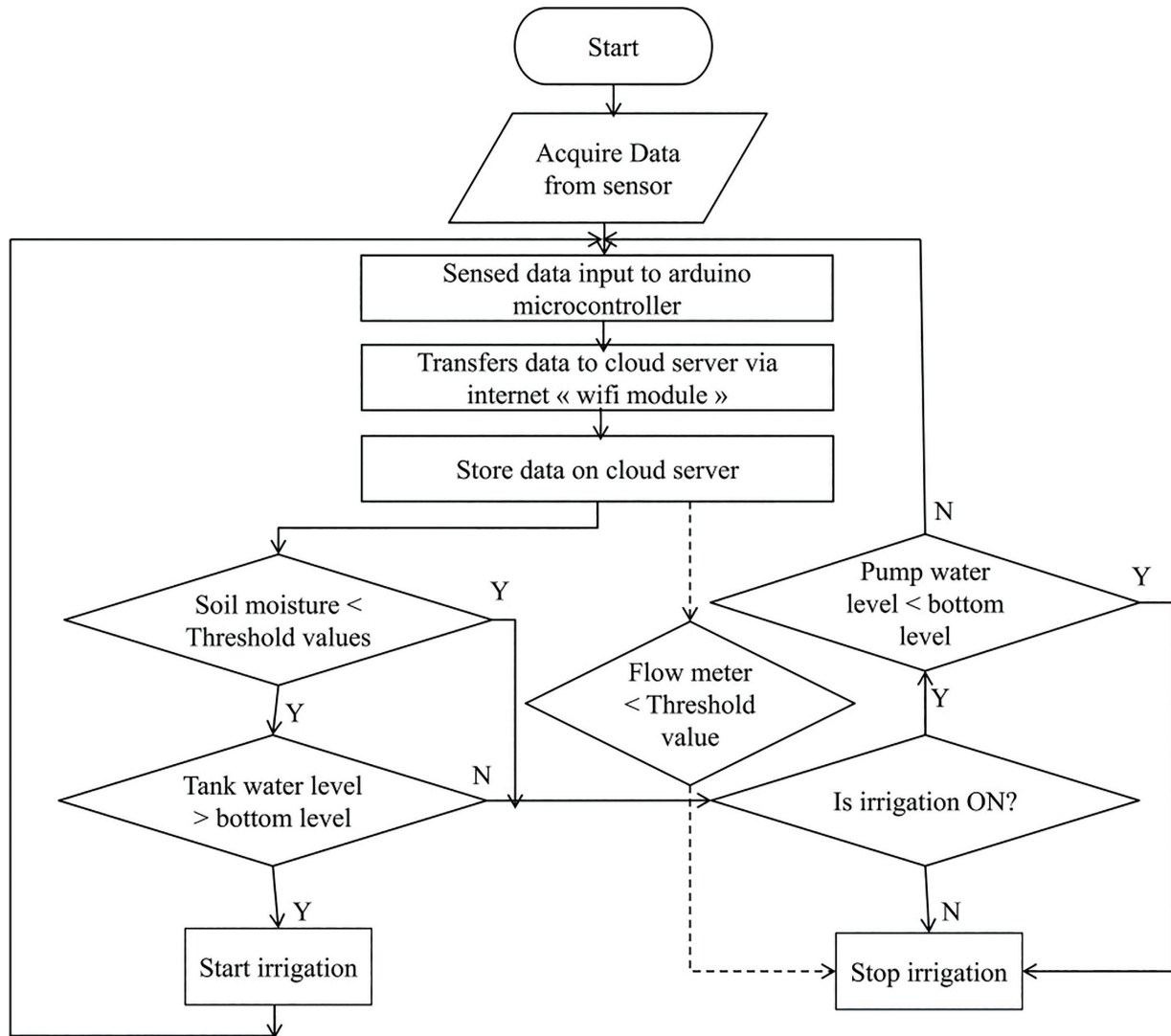


Figure 6: The organizational chart of irrigation algorithm.

studied. This was decided in order to have a common land feature dealing, e.g., with a same soil property. As indicated in Figure 7, (A) refers to a palm tree (kind Nour date) that has 2500 m² (0.25 ha) of area containing 50 palm trees, and (B) indicates pomegranate that has 1600 m² (0.16 ha) of area containing 45 pomegranates.

According to the studies and concrete examples of agricultural land, they showed that IoT has a very important role to support and help farmers in various types of agriculture. This role does not stop there, and farmers can take advantage and devote the time saved to other occupations to improve and increase their income.

The start and stop of the water sprinklers are now automatically controlled using the data that are

received in real time from IoT devices in each agricultural field. We first gathered all IoT data for 36 months (1095 days) and used this knowledge to analyze productivity. Every 20 min, temperature, humidity, and other IoT metrics were gathered, but only daily averages were utilized for analysis.

b. System design

The goal of this effort is to develop and deploy system technology with actuators and sensors dispersed over a crop field and data administration via a mobile with a web application. As illustrated in Figure 2, the hardware, web application, and mobile application are the three essential components of our system.

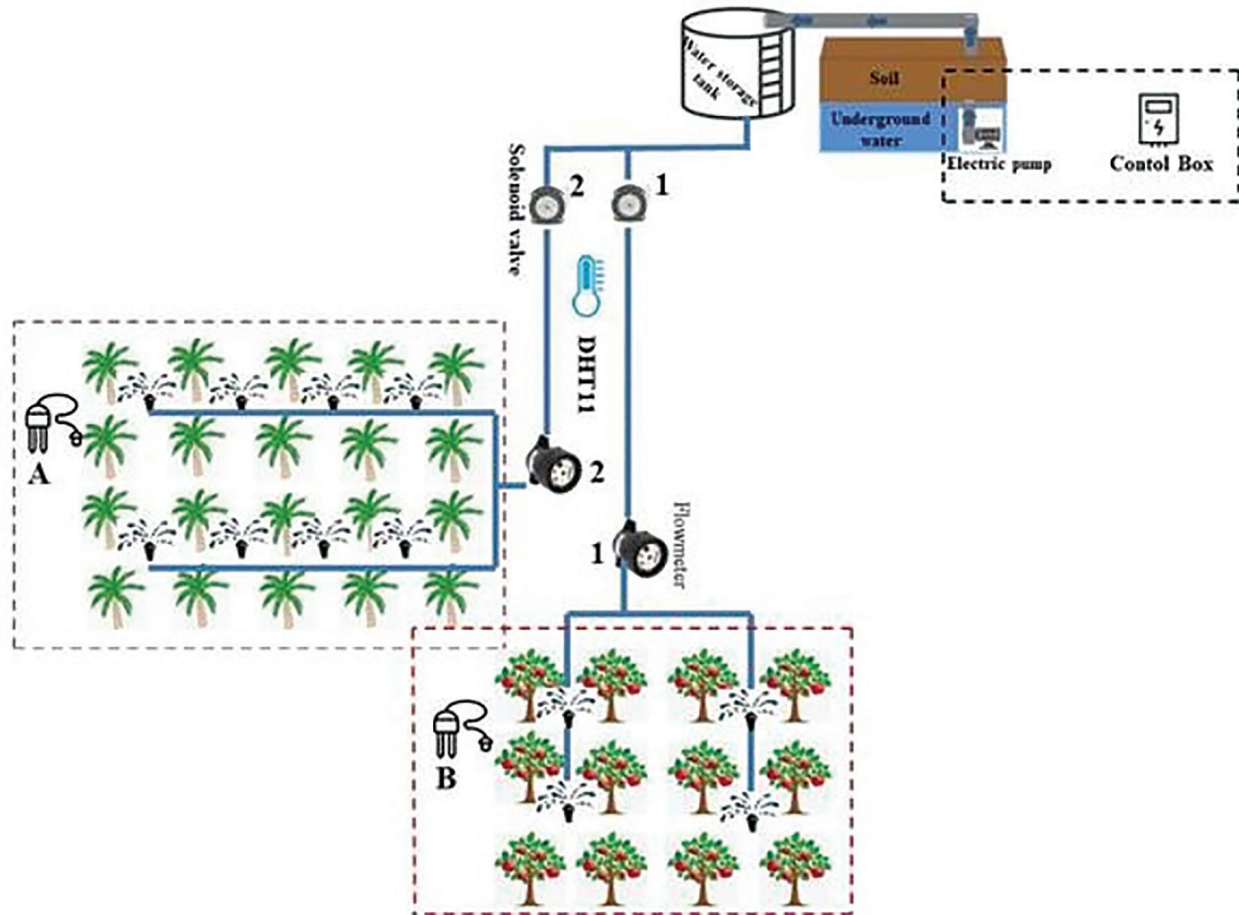


Figure 7: Farm's layout prototype and smart irrigation system.

Figure 2 shows a control box, and the latter is designed to obtain crop data and control IoT devices. IoT devices and control box used in this work are shown in Table 2.

The web application is the second component discussed. The latter involves real-time information management of IoT equipment in each farmland. An administrator allows manipulation of the water requirement conditions of each crop through the web application. Additionally, the administrator manage each type of agriculture thanks to the details of the information that comes from the IoT devices. To forecast future agricultural water needs, these data were evaluated.

The farmer's last tool is a cell phone, which the farmer uses to regulate irrigation after evaluating the data using a mobile application. Farmers may regulate irrigation by turning it on and off manually or automatically using this app's two options.

Table 2: Settings for deployment.

Parameter	Value	Voltage
Wi-Fi-module	ESP8266	3.3–5.5 V
Humidity and temperature	DHT11	5.5 V
Switch module × 5	(4) Channels	5.0 V
Solenoid valve	Brass valve 1/2 3/4	12 V
Flow meter	–	–
Water level sensor	Float switch	12 V
Architecture	Crop field	–

DHT, Digital Humidity & Temperature Sensor.

c. Implementation

The implementation of our proposed system is done in three areas, namely, a web application, a control

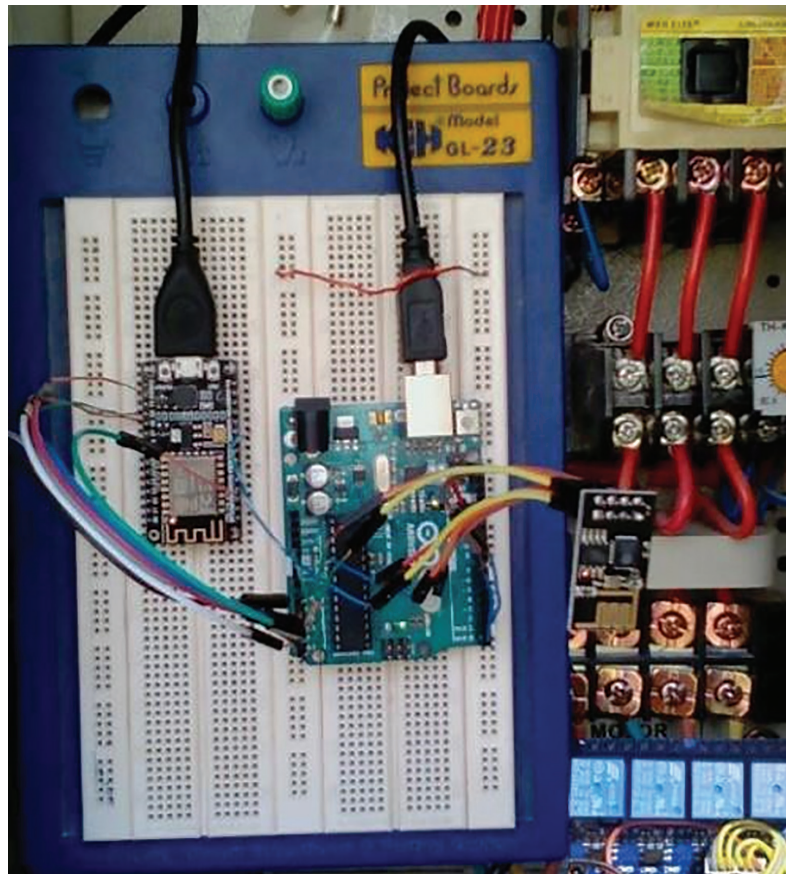


Figure 8: The control box design for installation.

box, and a mobile application. The control box, as seen in Figure 8, is used to store electronic equipment that must be operated in a waterproof container. The different sensors, including soil moisture, a solenoid valve, and a DHT11 sensor, are linked to the designated control box, which can be anywhere on the farm. In this work, we used IoT to automate the activation and deactivation of sprinklers and to assess soil moisture using soil moisture sensors. Utilizing a solenoid valve to turn water on and off is intended to manage water flow.

In this work, the primary responsible for managing the overall power flow is the charge controller. It is used to charge the battery of the photovoltaic panel; in addition, it is who manages the power supply of the load. When there is light, that is, in daylight, when the sun is present on the photovoltaic panel, if the voltage across the panel exceeds 12 V, the latter (the charge controller) has started charging the battery via the current output from the panel. The equipment of our irrigation system will be powered by the current coming from the photovoltaic panel, which can produce a sufficiently high voltage to charge the battery

on the one hand and control our irrigation system on the other hand Figure 9.

c.i Arduino UNO

An Arduino (Arduino LLC, Somerville, Massachusetts, USA) UNO is the microcontroller in use here. The UNO is an ATMEGA 328P-based microcontroller board. Code may be stored in 32kB of flash memory on the ATMEGA 328P. The board features a USB port, an In-Circuit Serial Programming (ICSP) circuit, a 16 MHz quartz crystal, 6 analog inputs, 14 digital input and output pins, an ICSP circuit, and a reset button. The Arduino software may be used to program the UNO.

c.ii Sensors

- *Soil moisture*

To gauge the amount of moisture in the soil, a soil moisture sensor is employed. The low level (0 V) is the digital output when the sensor detects soil moisture levels above the threshold level, and the high

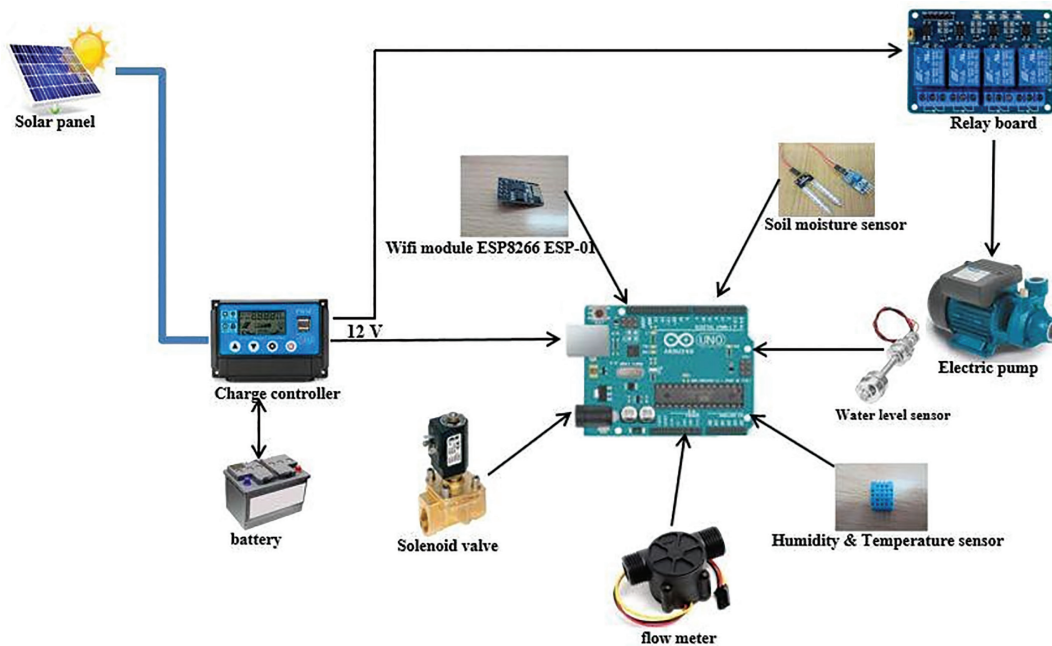


Figure 9: Overall system design.

level (5 V) is when soil moisture levels are below the threshold level.

To determine whether the present soil moisture value is above the threshold or not, the digital pin is utilized to read it immediately. Potentiometers can be used to control the threshold voltage.

- *DHT11 sensor*

Temperature and humidity are measured using a DHT11 sensor. To gauge the air around it, it makes use of a thermistor and a capacitive humidity sensor. This sensor is inexpensive, has minimal power requirements, and allows for signal transmission up to 20 m.

- *Flow meter*

An electrical device known as a flow sensor (sometimes known as a “flow meter”) detects or controls the flow rate of liquids and gases via pipes and tubes. Flow sensors may be linked to computers and digital interfaces in addition to gauges, which is how they are typically used to output measurements.

- *Solenoid valve*

An electrical control is used to operate solenoid valves. The valve is equipped with a solenoid, which

is an electric coil with a moveable ferromagnetic core (plunger) in its center. A tiny aperture is sealed off by the plunger while it is in the rest position. A magnetic field is produced by the flow of electricity via the coil. The plunger is pulled upward by the magnetic field, causing the orifice to be opened. To open and close solenoid valves, this fundamental idea is used.

- *Water level*

A level sensor is a device used to gauge, keep track of, and support the maintenance of liquid levels. The level of a river or lake may be measured as well as the level within containers.

c.iii Wi-Fi module

Any microcontroller may access any Wi-Fi network thanks to the ESP8266 Wi-Fi module, a self-contained system on chip (SOC) with an integrated Transmission Control Protocol/Internet Protocol (TCP/IP) protocol stack. Each ESP8266 module is preprogrammed, so all that is needed to add Wi-Fi functionality is to connect it to an Arduino device. This module can be combined with the sensors and other application-specific devices since it has a strong enough on-boarding procedure and a large storage capacity Figure 10.

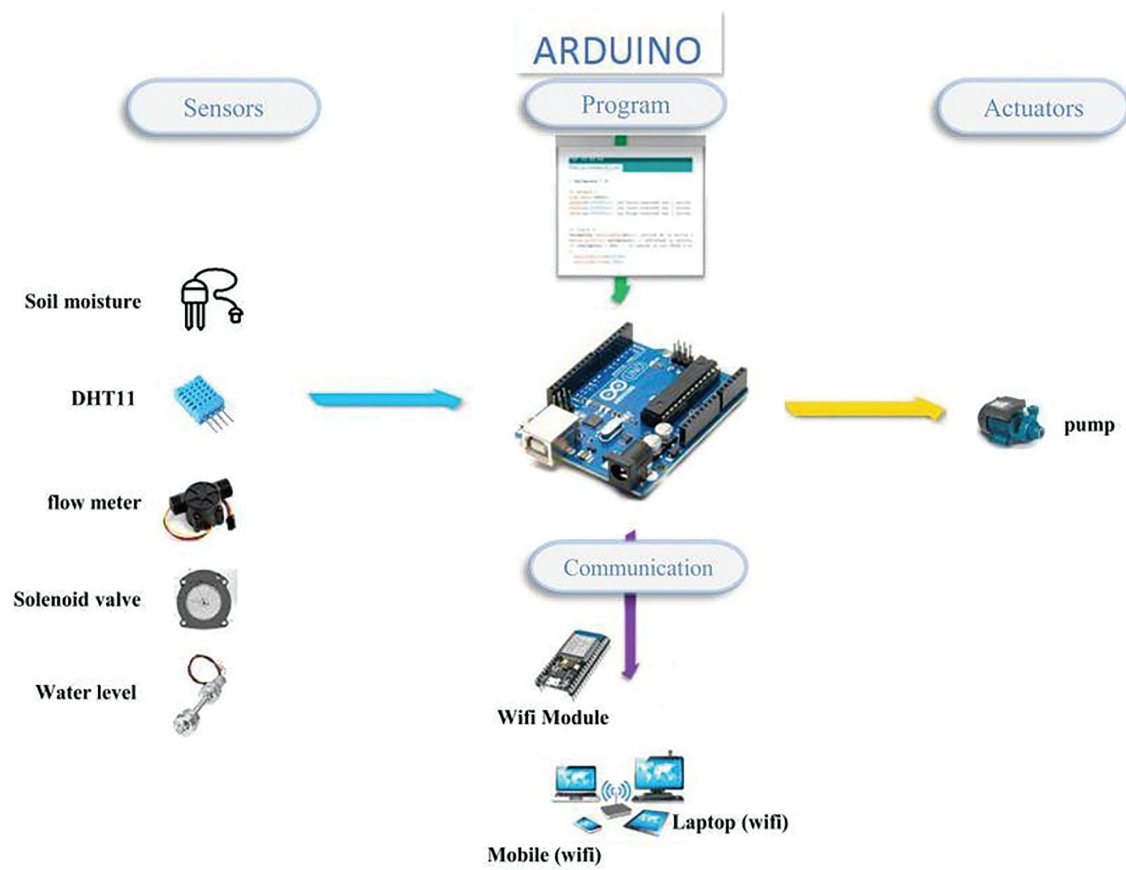


Figure 10: Detailed controller interface diagram.

By automatically sensing the surrounding humidity and temperature values, the soil moisture value, and the tank water level from the field, our system assists the user in increasing the quality and quantity of their agricultural production. Utilizing the IoT system idea may be more effective. The system includes field-installed sensors for real-time data collection, an ESP8266 Wi-Fi module for receiving and transmitting the collected data to the control section, a micro-controller, and a relay switching device. The cloud server stores the data that the Wi-Fi module sends. The cloud server compares the observed values to the predetermined threshold values in accordance with the crop selection before making a decision. The control action is communicated to the wireless sensor node after the data are evaluated and the choice is made at the control section using an irrigation algorithm. The sprinkler subsystem and relay switching unit are both under the control of the node micro-controller. The report system, an Android application, was created to give users access to the most recent field information. Additionally, it encourages the user to respond to crucial incidents like temperature

increases, water requirements for plants, and water leaks.

Taking into account the necessitated water's quantity by various plants and over different seasons will obviously give help to better optimizing farm production.

In our work, the depth of the well is about 80 m, so when we are talking about groundwater, in this situation, we must have an electric motor to pump the water from the well. As you know, the drying up of the well represents an imminent danger to the pump, and for this, it is necessary to monitor the level of the water at depth. The cooling effect of flowing water is an important factor for the pump motor to maintain their operating temperature. In the absence of water at the level of the pump, that is, it can run dry and either stop working due to overheating, or burn. In addition, the lack of flowing water will result in damaged mechanical seals, causing excessive friction and consequently an increase in pump motor temperature, but most motors that operate irrigation pumps are cooled by water during their work. Therefore, without monitoring of all our system (sensors, actuators, etc.)



Figure 11: Different real studied cases.

Table 3: The predefined parameters and the products (palm and pomegranate).

Years	Palm 's products (Date Nour) and predefined parameter					Pomegranate's products and predefined parameter				
	Temp (°C)	DHT (%)	Hum_sol (%)	Water_irr (m³/tree)	Kg/ tree	Temp (°C)	DHT (%)	Hum_sol (%)	Water_irr (m³/tree)	Kg/ tree
Winter	12	65.82	–	8.67		12	65.82	–	2.6	
Autumn	22.66	51.49	–	4.8	80.5	22.66	51.49	–	3.03	
2016										18.14
Spring	20.33	46.28	–	8.15		20.33	46.28	–	5.82	
Summer	30.66	42.72	–	7.29		30.66	42.72	–	7.19	
Winter	10.77	62.93	–	7.52		10.77	62.93	–	3.25	
Autumn	21.4	55.88	–	4.13		21.4	55.88	–	1.94	
2017					110.5					15.87
Spring	22.17	48	–	8		22.17	48	–	2.89	
Summer	31.37	39.55	–	8.3		31.37	39.55	–	6.02	
Winter	11.91	60.13	–	6.41		11.91	60.13	–	1.88	
Autumn	22.71	52.81	–	3.89		22.71	52.81	–	2.09	
2018					99					20.41
Spring	21.15	47.08	–	7.94		21.15	47.08	–	2.91	
Summer	31	43.9	–	9.01		31	43.9	–	5.79	

Table 4: The measured parameters and the products (palm and pomegranate).

Years	Palm's products (Date Nour) and measured parameters					Pomegranate products and measured parameters				
	Temp (°C)	DHT (%)	Hum_sol (%)	Water_irr (m ³ /tree)	Kg/ tree	Temp (°C)	DHT (%)	Hum_sol (%)	Water_irr (m ³ /tree)	Kg/ tree
Winter	11.89	53.47	85.11	5.81		11.89	53.47	79.42	0.16	
Autumn	22.52	54.11	59.56	3.09	125.5	22.52	54.11	61.08	0.8	
2019										27.3
Spring	19.72	46.17	80.47	6.92		19.72	46.17	69.75	2.4	
Summer	32.23	37.45	52.6	7.15		32.23	37.45	59.82	5.28	
Winter	12.11	57.67	74.27	5.17		12.11	57.67	71.41	0.85	
Autumn	22.85	53.15	67.87	3.90		22.85	53.15	59.17	1.04	
2020					127					29.48
Spring	21.27	48.67	69.58	4.98		21.27	48.67	62.3	3.29	
Summer	31.16	41.02	55.57	7.06		31.16	41.02	55.8	6.42	
Winter	12.65	51.09	81.19	6.95		12.65	51.09	80.05	1.98	
Autumn	24.10	51.85	66.4	3.28		24.10	51.85	62.71	2.77	
2021					126.5					31.75
Spring	22.29	54.16	68.82	7.05		22.29	54.16	63.6	2.69	
Summer	35.29	38.56	52.59	8.20		35.29	38.56	59.47	6.88	

automatically causes increased maintenance costs for farmers.

Therefore, based on what we said earlier, it has become clear that monitoring and automatic control of irrigation is essential. In addition, the system allows the user to intervene remotely in the event that there is abnormal behavior by sending a simple notification.

d. Agricultural data statistic

We have been able to draw forth significant and practical insights from huge crop data thanks to the applicability of IoT technology Figure 11. The four steps of data mining are as follows:

- Data preprocessing.
- Data reduction.
- Data modeling/discovery.
- Solution analysis

Analytical theoretical model was applied to practical selected parameters such as temperature, humidity, soil humidity, water source, total agricultural area, and periodical monthly watering. We found the

following value maximizing the hoped income named Max Z as mentioned in Table 5.

IV. Results

V. Discussion

We see that after installing IoT devices, management becomes easier. The entry has been increased as we can see in Table 5, for example, income from palm production. The conclusion can be better explained when we see that the average production obtained has increased about 17,534 between 2016 and 2018 to a new value of 28,840 from 2019 to 2021. So, there is a difference of $d = 11,306$. The production has been increased by an amount almost 65%. Also, the pomegranate production revenue shows this growth by applying the IoT devices and the proposed model. These results provide useful information for anyone to retain these new technological solutions that clearly enhance revenue. We do not forget that we also used solar energy to provide electricity and we earned a lot of money on the energy consumption side.

Table 5: The production income (palm and pomegranate).

Years	Ppi (Date Nour)	Max Z	Δ	% Δ	Popi (TND)	Max Z	Δ	% Δ
2016	14892	~14830	62	0.42	1387	~1265	122	0.82
2017	19890	~19780	110	0.55	1249	~1270	21	1.68
2018	17820	~17960	140	0.78	1441	~1389	52	3.61
2019	31375	~30975	400	1.27	2149	~2158	9	4.19
2020	29845	~28741	1104	3.7	2653	~2710	57	2.15
2021	25300	~26050	750	3	2640	~2609	31	1.17

TND, National currency of Tunisia.

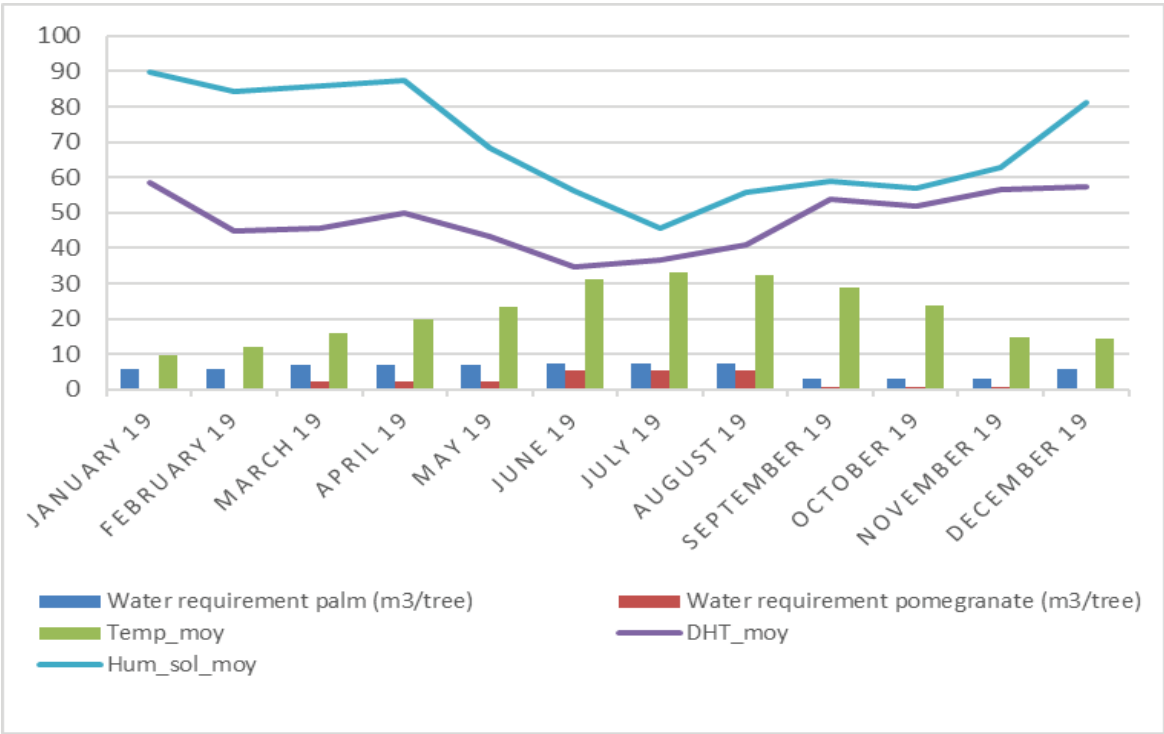


Figure 12: An illustration of a mobile irrigation control application.

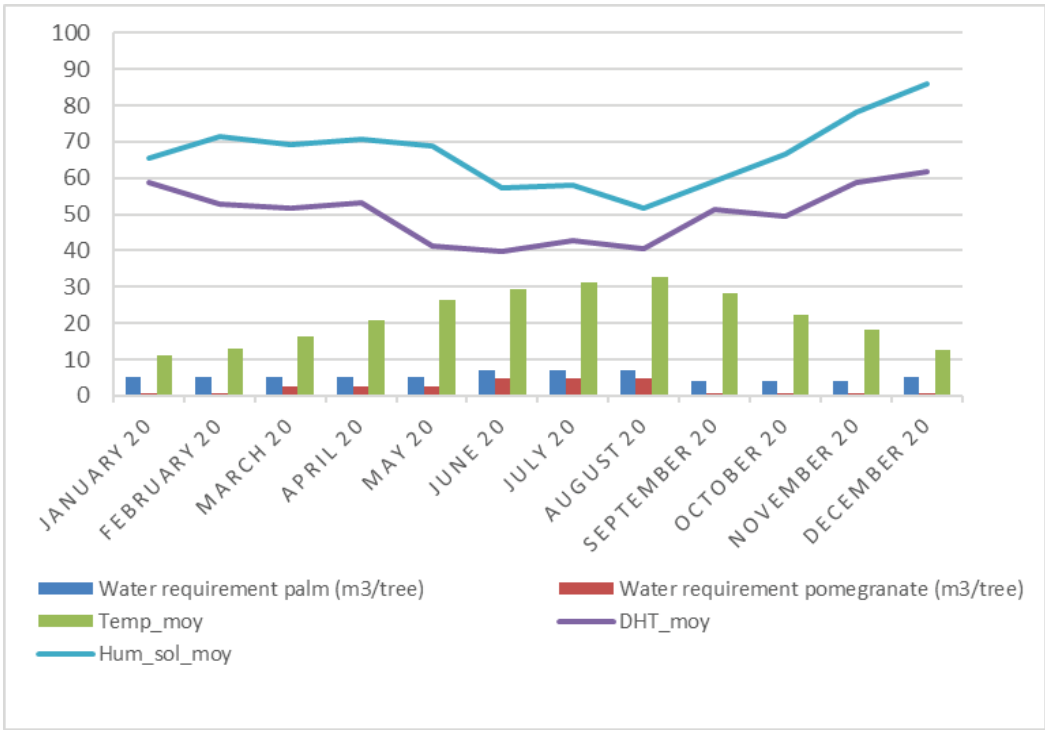
VI. Conclusions and Future Work

The IoT has been used in agriculture to increase agricultural yields, enhance crop quality, and cut expenses. For these reasons, we have suggested in this article that WSNs that are based on the IoT can be used to irrigate crops. For environmental elements in crop fields, such as temperature, humidity, and soil moisture, we have created and implemented a control system. The system was composed of the following

three components: hardware, a mobile application, and a web application. The initial component was created and constructed as a control box. This control box has hardware and an electronic control system for sensor connections and data collection for agriculture. The control box was designed for testing under realistic conditions. The established system was able to connect to and receive IoT data from any research domain. The web application that was created and put into use to alter crop data and field

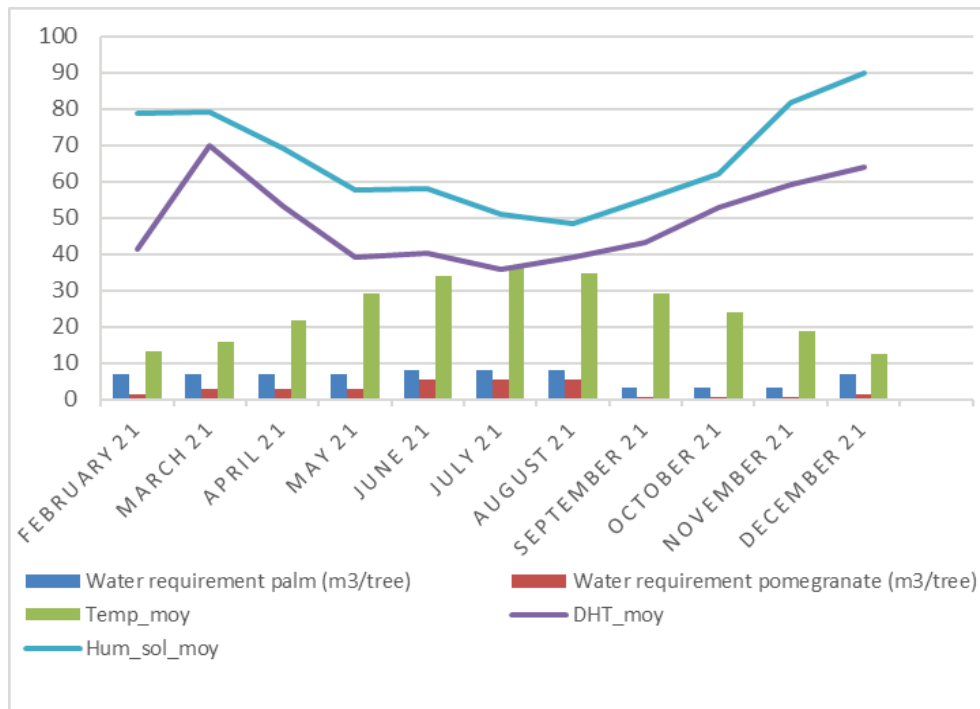


(A)

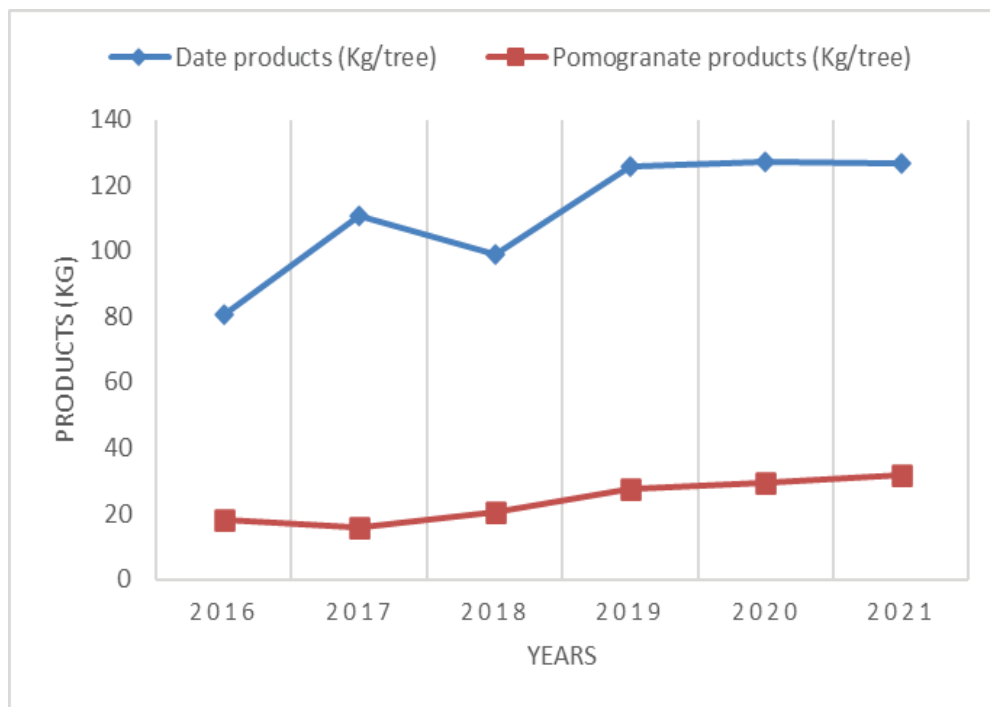


(B)

Figure 13: Continued.



(C)



(D)

Figure 13: IoT data that boost productivity. IoT, Internet of Things.

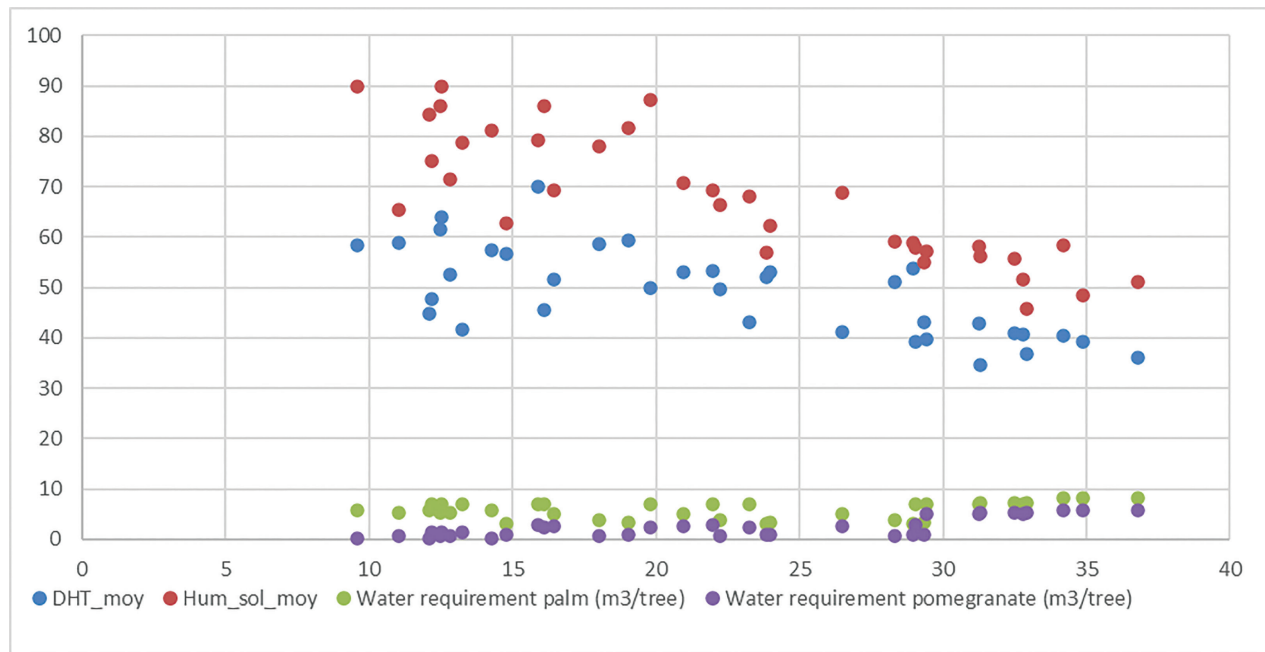


Figure 14: IoT information, variations, and simulation of data between them. IoT, Internet of Things.

information made up the second component. Large-scale IoT data are saved and used for data analysis in this stage. This work made a significant contribution by using data mining by association rules to unearth helpful information Table 3 and Table 4. The findings show that throughout the three years (2019, 2020, and 2021), when we managed the watering owing to the appropriate placement and installation of IoT technology in the farm, a good production of dates (Date Nour) and pomegranates is produced, as shown in Figure 13 curve (D). Additionally, the curves (A), (B), and (C) clearly demonstrate the effective water management for the irrigation of palm and pomegranate crops; whereas for the years (2016, 2017, and 2018) during conventional irrigation, there was a significant water waste. We will be able to manage crop irrigation thanks to our mobile app on a smartphone (Figure 12). Due to this, the user may operate in both automated and manual modes. The automated feature for watering may be used by the user and is based on information from soil moisture sensors. In the functional control mode, manual control was nonetheless feasible. The system used the app's Application Programming Interface (API) to send alerts. The outcomes demonstrated definite advantages for agriculture. The soil moisture content has been properly controlled for palms and pomegranates, resulting in cheaper expenses and increased agricultural output Figure 14. This case

study highlights the vast possibilities for agricultural uses of digital technology.

While our study has provided valuable insights into the application of IoT-based smart irrigation systems in agricultural practices, it is essential to acknowledge its limitations and opportunities for future enhancements. One limitation of our study is the relatively short duration of data collection, spanning three years (2019, 2020, and 2021). Although this timeframe offered valuable insights into the effectiveness of our smart irrigation system, longer-term data collection would provide a more comprehensive understanding of its performance across various environmental conditions and agricultural cycles.

Additionally, future research endeavors could aim to replicate our study in diverse geographical locations and crop types to assess the broader applicability of our approach. In terms of future improvements, we plan to enhance the robustness and reliability of our smart irrigation system through ongoing technological advancements and refinements. This includes incorporating additional sensors and actuators to capture a wider range of environmental variables and optimize irrigation scheduling further. Moreover, we aim to explore machine learning and predictive analytics techniques to develop more sophisticated decision support systems for farmers. Our findings underscore the vast potential of IoT-based smart irrigation systems to revolutionize agricultural practices

by increasing yields, enhancing crop quality, and reducing expenses. By addressing limitations and embracing future improvements, we remain committed to advancing sustainable water management practices and contributing to the broader adoption of digital technology in agriculture.

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Competing Interests

The author has no relevant financial or nonfinancial interests to disclose.

Data Availability

The datasets generated during and/or analyzed during the current study are available with the author.

References

- [1] Ministère de l'Agriculture des Ressources Hydrauliques et de la Pêche, 2021. *Projet Annuel de Performance de la mission Agriculture, Ressources hydrauliques et Pêche pour l'année 2022*.
- [2] FAO. *World Agriculture: Towards 2015/2030—An FAO Perspective*; Earthscan Publications Ltd.: London, UK, 2014.
- [3] Alomar B. and Alazzam A., 2018. A Smart Irrigation System Using IoT and Fuzzy Logic Controller. *The Fifth HCT INFORMATION TECHNOLOGY TRENDS (ITT 2018)*, Dubai, UAE, Nov., 28 - 29, 2018.
- [4] Pernapati K., 2018. IoT based low cost smart irrigation system *Proceedings of the 2nd International Conference on Inventive Communication and Computational Technologies (ICICCT 2018) IEEE Xplore Compliant - Part Number: CFP18BAC-ART*; ISBN:978-1-5386-1974-2
- [5] H. Van Es and J. Woodard, "Innovation in agriculture and food systems in the digital age," *The global innovation index*, pp. 97–104, 2017.
- [6] M. Monica, B. Yeshika, G. S. Abhishek, H. A. Sanjay and S. Dasiga, "IoT based control and automation of smart irrigation system: An automated irrigation system using sensors, GSM, Bluetooth and cloud technology," *2017 International Conference on Recent Innovations in Signal processing and Embedded Systems (RISE)*, Bhopal, 2017, pp. 601-607. doi: 10.1109/RISE.2017.8378224.
- [7] D. Trincherio and R. Stefanelli, "Integration between Internet of Things and Internet of services for an enhanced optimization of water and gas distribution," *2012 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, San Francisco, CA, 2012, pp. 1-6. doi: 10.1109/WoWMoM.2012.6263788.
- [8] Agrawal, K. & Kamboj, N. (2019). Smart agriculture using IOT: A futuristic approach. *International Journal of Information Dissemination and Technology*, 9(4), 186-190
- [9] Benhmad, T., Ben Abdenmour, A., Darghouthi, A., Belgacem Rhaimi, C., "Remote control of environmental parameters in rabbitry based on IoT". *Journal Internet of Things and cyber-physical Systems* vol. 2, pp. 111-119, June 2022 DOI: 10.1016/j.iotcps.2022.06.003.
- [10] Hwang, J., Shin, C., & Yoe, H. 2010. Study on an Agricultural Environment Monitoring Server System Using Wireless Sensor Networks. *Sensors*. 10(12): 11189-11211
- [11] USC Precision Agriculture. Available online: <http://www.gpoaccess.gov/uscode/index.html> (accessed on 3 December 2010)
- [12] Fourati, M.A., Chebbi, W., Kamoun, A., 2014. Development of a web-based weather station for irrigation scheduling. In: *Information Science and Technology (CIST), 2014 Third IEEE International Colloquium in IEEE*, pp. 37–42.
- [13] Chen, K.T., Zhang, H.H., Wu, T.T., Hu, J., Zhai, C.Y., Wang, D., 2014. Design of monitoring system for multilayer soil temperature and moisture based on WSN. In: *International Conference on Wireless Communication and Sensor Network (WCSN). IEEE, Wuhan*, pp. 425–430. DOI: 10.1109/WCSN.2014.9.
- [14] Qi Ma, *Research of Greenhouse Temperature and Humidity Monitoring System Based on Wireless Sensor Networks*, North University, 2009.
- [15] N. Putjaika, S. Phusae, A. Chen-Im, P. Phunchongharn and K. Akkarajitsakul, "A control system in an intelligent farming by using arduino technology," *2016 Fifth ICT International Student Project Conference (ICT-ISPC)*, Nakhon Pathom, 2016, pp. 53-56.
- [16] K. K. Rout, S. Mallick, and S. Mishra, Solar powered smart irrigation system using Internet of Things, In *2018 2nd International Conference on Data Science and Business Analytics (ICDSBA)*, pp. 144-149, IEEE, Sep 2018.
- [17] N. Sudharshan, A. K. Karthik, J. S. Kiran, and S. Geetha, *Renewable Energy Based Smart Irrigation*

System, *Procedia Computer Science*, vol. 165, pp. 615-623, Jan 2019.

[18] E. U. Singh, M. Vyas, G. Sharma, S. P. Singh, and S. Khan, Solar Based Smart Irrigation System, *International Journal of Recent Research Aspects (IJRRA)*, vol. 3(1), pp. 105-108, March 2016.

[19] Veeramanikandasamy T, Rajendran, K.; Sambath K., Sangeetha, D., " Remote monitoring and closed loop control system for social modernization in agricultural system using GSM and Zigbee technology", *International Conference on Advances in Electrical Engineering (ICAEE)*, pp. 1 - 4, 2014 Usman Zafar

[20] Usman, Z., Muhammad A., Muhammad J.M.C., Riaz A.T., 2020. Sensor based drip irrigation to enhance crop yield and water productivity in semi-arid climatic region of Pakistan, *Pak. J. Agri. Sci.*, Vol.57(5), 1293-1301; 2020. doi:10.21162/pakjas/20.83.

[21] J. Gutiérrez, J. F. Villa-Medina, A. Nieto-Garibay and M. Á. Porta- Gándara, "Automated Irrigation System Using a Wireless Sensor Network and GPRS Module," in *IEEE Transactions on Instrumentation and Measurement*, vol. 63, no. 1, pp. 166-176, Jan. 2014.

[22] J. John, V. S. Palaparthi, S. Sarik, M. S. Baghini and G. S. Kasbekar, "Design and implementation of a soil moisture wireless sensor network," 2015 Twenty First National Conference on Communications (NCC), Mumbai, 2015, pp. 1-6.

[23] Nakutis et al., "Remote Agriculture Automation Using Wireless Link and IoT Gateway Infrastructure," 2015 26th International Workshop on Database and Expert Systems Applications (DEXA), Valencia, 2015, pp. 99-103.

[24] P. Y. Dattatraya, J. Agarkhed and S. Patil, "Cloud assisted performance enhancement of smart applications in Wireless Sensor Networks," 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), Chennai, 2016, pp. 347-351.

[25] Fisher F., A. H.Lee., Amir I., Arlosoroff S. Eckstein Z., Haddadin M., Hamati S., Jarrar A., Jayyousi A., Shamir U., and Wesseling H, 2005. "Liquid Assets: An Economic Approach for Water Management and Conflict Resolution in the Middle East and Beyond". Resources For The Future, Washington, DC USA, 2005.

[26] Salman, A., Al-Karablieh, E., Fisher, F., "An inter-seasonal agricultural water allocation system (SAWAS)". *Agricultural Systems*. Vol. 68 (3), 233-252., 2001.

[27] Allen, R.G., Pereira, L.S., Raes, D., Smith, M., et al., 1998. Crop evapotranspiration guidelines for computing crop water requirements-fao irrigation and drainage paper 56. FAO, Rome 300 (9), D05109.

[28] Bogawski, P., Bednorz, E., 2014. Comparison and validation of selected evapotranspiration models for conditions in poland (central Europe). *Water Resour. Manage.* 28 (14), 5021-5038.

[29] Gafar K.Y. (2010). Besoins en eau du palmier dattier en Emirats Arabes Unis. The Blessed Tree, Khalifa International Date palm Award 02: 80-92.

[30] Ismail S.M., Al-Qurashi A.D. and Awad M.A., (2014). Optimization of irrigation water use, yield, and quality of "Nabbutsaif" date palm under dry land conditions. *Irrigation and Drainage* 63: 29-37.

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