Towards a Smart Irrigation System based on Wireless Sensor Networks (WSNs)

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Abstract: Due to the evolution of technologies and need to observe and manage hostile environments, Wireless Sensor Networks (WSNs) are becoming essential and implicated in most fields of life. The agricultural sector is one of such sectors where WSNs are successfully utilized to achieve many benefits. For successful agriculture, the irrigation is one of the most important factors, where it plays a tactical role in the process of agriculture but is considered one of the world's largest freshwater consumers. Besides, the water scarcity, drought, and irrational wastage of water resources are among the critical issues that touch almost all sectors, notably agricultural services, and especially irrigation. These facts lead all governments around the world to rethink about saving water and reducing the amount of water used in irrigation; this requires the development of irrigation practices in order to obtain a complete and independent system for the management of irrigation more efficient. Consequently, selection of using WSNs in irrigation system will be a benefit for developing the agriculture, and thus saving water and improving and increasing production. In this work, we propose a new model of a complete and smart irrigation system based on wireless sensor networks, and we introduce and discuss our proposed system. The suggested system controls and regulates irrigation system by monitoring a set of environmental parameters, i.e., soil and weather properties, using soil and weather sensor nodes and improving techniques of decision-making to estimate requirements of each crop (e.g., amount of water required), and therefore can make the decision to activate or disable irrigation.

1 INTRODUCTION

Irrigation is one of the most vital services in the agricultural sector. It has become an indispensable part in agriculture, and it also plays a very important role in increasing crop production and improving yields (FAO et al., 2018) in order to meet growing food requirements of the ever-growing world population (Dabour, 2002). Irrigation is defined as the action of the artificial water supply for farmland. This is an important practice in most agricultural crops in regions where the rate of rainfall is not enough to fulfill the water needs of crops.

Water scarcity (Rijsberman, 2006) has become a severe global crisis which attracts worldwide attention. The freshwater represents only about 2.5% of the total water on Earth, where most of this water is unavailable for use because it is stored as deep groundwater or glaciers and only a small amount of this is available for human use (Vörösmarty et al., 2000). The agriculture is considered one of the most water consuming sectors in the world; this water is mainly used for irrigation (Food and Agriculture Organization, 2018). Water used for irrigation currently accounts for about 70% of global water withdrawals and almost 90% of the use of consumptive water (Haddeland et al., 2014). However, irrigation techniques currently used remain ineffective with low performance; these techniques are intended only to control the distribution of water at required locations without compromising water requirements, and thus losing a significant amount of water during each irrigation operation. Furthermore, several areas may be affected by increasing or decreasing the amount of water used during irrigation, while under irrigated regions are subject to poor production and water stress and over irrigated regions are affected by plant diseases. Drought (Mishra and Singh, 2010), pollution and water contamination, climate change (Kalra et al., 2007; Haddeland et al., 2014), and the risks of salinity all of these reasons lead to a

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dangerous decline in water resources, day after day, and also seriously affect the agricultural sector, especially irrigation.

To address these issues and problems, new and modern technologies must be used to support irrigation by developing and improving techniques to intelligently monitor environmental parameters (e.g., moisture and temperature of soil, and temperature and humidity of weather) and decision-making capabilities in order to determine the amount of water needed for each crop in a particular area at a particular time, while saving water and increasing the yield and the quality of crop productivity. In this regard, Wireless Sensor Network (WSN) technology is an ideal modern technology that merges a set of capabilities such as automatic control, sensor capabilities, information processing, and data storage to get many benefits and offer economical and effective solutions for the irrigation system. Therefore, the utilization of WSN supports agriculture, and thus irrigation, and leads it in a very positive direction and promotes irrigation to a higher level of efficiency, automation, precision, and intelligent production (Wang et al., 2006; Ruiz-Garcia et al., 2009; ur Rehman et al., 2014).

The main contribution of this work is to propose and develop a new smart irrigation system based on the use of the wireless sensor network to solve and address the problems of irrigation systems. In this paper, we present a new model of an autonomous and intelligent irrigation system through the development of a monitoring system for a set of environmental parameters in real-time, i.e., soil properties and properties of the weather, using different sensors scattered on agricultural land and the improving techniques of remote decision-making during irrigation. Our proposed system allows irrigation control and management through the rational use of water by measuring and checking soil and weather properties and estimating the amount of water required for each crop. Therefore, this solution aims to save water, increase the performance of the irrigation system, reduce costs, increase and improve production, and conserve energy and time.

The remaining part of this paper is organized as follows. In the next section, an overview of sensors and wireless sensor networks is presented and explained. In Section 3, we present the related work with critical analysis. Section 4 provides and describes the proposed smart irrigation system based on wireless sensor networks. Finally, in Section 5, the paper is concluded and a discussion of our future work is presented.

2 WIRELESS SENSOR NETWORK TECHNOLOGY

In recent years, the tremendous progress in wireless technologies and the proliferation of micro-electro-mechanical systems (MEMS) technology have enabled and facilitated the development of low-cost smart sensors with low energy consumption. These sensor nodes are autonomous and inexpensive nodes with a miniature size, and have computing and processing resources. They measure or detect physical information in a controlled environment and convert it into signals for surveillance and control.

Wireless Sensor Network (WSN) is a special type of Ad Hoc network, which allows monitoring and controlling hostile environments and remote areas. The WSN consists of a large number of sensor nodes that can be self-organized and connected to each other via a wireless connection module. These nodes have various capabilities: communication, detection, transmission, and processing capability, and can be deployed either randomly or accurately. In this type of network, the sensor nodes are dispersed over the field, specifically in a sensor field. Each node uses its abilities (e.g., sensation, processing, and data transmission) to collect and route data for the purpose of creating a global view of the controlled area. The data collected by these sensors are routed directly or via other sensors by a multi-hop architecture to a "collection point", called a base station for subsequent processing. The base station also acts as a gateway node whenever it is necessary to communicate and connect with the external network for data analysis and decision-making (Akyildiz et al., 2002a; Yick et al., 2008; Akyildiz and Vuran, 2010), as shown in Fig. 1.

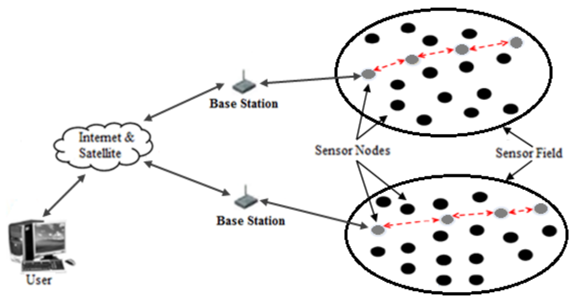

Figure 1: Structure of Wireless Sensor Network (WSN).

The sensor node is a micro-electro-mechanical system (Bhattacharyya et al., 2010) that detects or measures physical attributes and converts them into signals. It is the basic unit of WSN and appears as a miniaturized autonomous system with advanced sensation capabilities. A sensor node consists mainly of four basic units (refer to Fig. 2): a sensing unit, a transmission unit (transceiver), power unit (battery), and processing unit (Akyildiz et al., 2002b). In addition to these components, optional modules can be added to the sensor node (e.g., location finding system, external memory, and mobilization module for displacement). Sensing unit is the main component of a sensor node; it usually consists of two subunits: a sensor and an analog-to-digital converter (ADC). The processing unit comprises a processor (computing unit) and a memory (storage unit), it allows collaboration with other nodes to perform the appropriate tasks. The transmission unit connects the sensor node to the wireless sensor network. And the power unit is considered one of the most important components of the node, where it can power all its components.

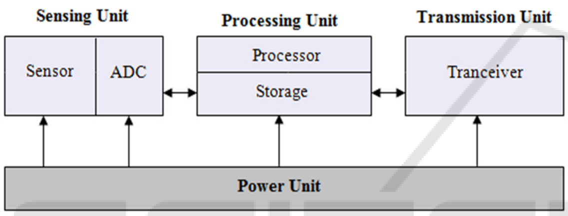

Figure 2: Components of a sensor node.

Due to the numerous characteristics of wireless sensor networks such as the ability to adapt to various environments, scalability, advantages of detection and wireless communication, ability to handle node failures, flexibility, and dynamic topology (Mishra and Thakkar, 2012; Manshahia, 2016) WSNs can be used widely in several applications. These applications include different areas like military, environment, agriculture, industrial, and medical, and have a wide range of uses such as battle monitoring, natural disaster discoveries, smart homes, healthcare, weather forecasts, and intrusion detection (Akyildiz et al., 2002b; Chong and Kumar, 2003; Arampatzis et al., 2005; Yick et al., 2008).

3 RELATED WORK

With advances in various areas of technology, wireless sensor networks have achieved a paradigm shift in the agricultural sector. WSNs play a crucial role in finding new solutions to develop and improve areas of agriculture and thus achieve more profits. Especially when it comes to irrigation, the idea of having an automated and intelligent irrigation system is very tempting to improve the system efficiency, obtain accurate results, and conserve water resources. A set of research on the use of WSNs to help and improve irrigation system has been conducted.

Mahir et al. (Dursun and Ozden, 2011) presented and described an application of a wireless sensor network to automate the drip irrigation system in an agricultural site of dwarf cherry trees. The developed system enables wireless control of irrigation technique and monitoring soil water content in real time using soil moisture sensors. In this system, many benefits have been achieved such as salification, prevention of moisture stress from trees, and effective use of freshwater resources.

Remote sensing and control system based on a distributed wireless sensor network, Bluetooth and GPS technologies has been developed for the irrigation system in (Kim et al., 2008). The WSN is composed of a set of sensor nodes dispersed in the agricultural land; these nodes monitor and observe conditions of the soil and the weather. The system can also detect the position of the sprinkler.

Various types of sensors used in the field of agriculture have been studied. The operations of some sensors, their basic principles, and their specifications have also been analyzed and discussed (Kodali et al., 2014).

Aqeel et al. (ur Rehman et al., 2014) presented a thorough study on the use of wireless sensor network in different aspects of agriculture like irrigation. Numerous techniques, approaches, and systems have been examined. Similarly, Ruiz-Garcia et al. (Ruiz-Garcia et al., 2009) presented a review of WSN applications in the agriculture sector. Various available systems based on WSNs and RFID as well as examples of applications have been explained and analyzed.

The authors of (Gutiérrez et al., 2014) developed an automated irrigation technique based on the use of wireless sensor network and GPRS to optimize irrigation water for agricultural crops (Sage crop). Developed system consists of a distributed wireless network with multiple temperature and soil moisture sensors to effectively control and monitor soil conditions. The detected data are transferred to a control unit for analysis, identification, and recording of these data. The control unit also allows the activation of the irrigation. The results of this system showed a significant saving of water compared to traditional irrigation methods (up to 90%). And in another work (Avatade and Dhanure, 2015), Avatade et al. examined the design of the irrigation system in an automated manner based on an embedded platform using WSN, ARM microcontroller, and GPRS. The developed system consists of a set of ARM microcontroller-based wireless sensor nodes deployed in the field to measure the temperature and moisture level of the soil. Based on the measured values, the WSN controls the flow of water in the field to reduce the consumption of water during irrigation. This system also permits monitoring the measured data and the status of the sensors used on the remote PC via a web page by entering the specified IP-address for the system.

Imteaj et al. (Rahman et al., 2016) proposed and described an automatic water supply system for irrigation in agricultural land based on the use of Raspberry Pi, Wi-Fi module, Arduino, and GSM. This system consists of several sensors to detect and monitor soil moisture, daylight intensity, and water level in the soil. The measured data are sent as a digital signal via Wi-Fi to the Raspberry Pi. Based on these data, the system can determine the suitable moment for irrigation water supply. Via GSM using SMS, the developed system allows alerting the administrator in case of problems in the water supply (e.g., shortage of water) and the administrator can also communicate with this system.

The authors of (Katyara et al., 2017) implemented wireless sensor network as a remote terminal unit (RTU) for remote monitoring and intelligent control of irrigation system in Pakistan. Various data, such as soil moisture and temperature, were measured by these RTUs and these data are sent to estimate and control the amount of water needed during irrigation activity. The results of the tests showed positive results in terms of reducing water used in irrigation and increase the productivity of agricultural land (Increased almost 20 to 25%).

Minu et al. (Nagarajan and Minu, 2018) developed an automated soil properties monitoring system using WSN to automate sprinkler irrigation system, thereby improving and controlling water supply and yield. The developed system uses a range of sensors to detect and monitor the pH, temperature, and humidity of the soil. The sensed data are sent to an operator for surveillance purposes (e.g., soil water content monitoring). This system also uses ZigBee and GPRS technologies for data transmission, analysis, and storage.

And in (Cambra et al., 2018), Sandra et al. proposed a solution that allows automating the irrigation technique to ameliorate the sustainability of hydroponic agriculture. In which they developed a smart control system for bicarbonate during irrigation using a wireless sensor network to take advantage of hydroponic precision farming in greenhouses. This system is based on the use of an auto-calibrated pH sensor that allows detection and modification the imbalances of pH levels in nutrient solutions used for hydroponic agriculture. The auto-calibrated pH sensor is connected to a wireless node. The WSN consists of multiple nodes connected to each other.

4 PROPOSED MODEL OF INTELLIGENT IRRIGATION SYSTEM

Current irrigation systems are considered inefficient and poorly performing systems with irrational water consumption. It is necessary to combine a set of criteria such as an effective management and control of the irrigation water system, good selection of irrigation system, and automation of irrigation in order to save water, increase irrigation system performance, and develop and improve production. Therefore, using a wireless sensor network in irrigation systems supports irrigation very well. In this context, our proposed solution is based on the development of a new smart irrigation system based on WSN, with the development of monitoring techniques and amelioration of decision-making capabilities during irrigation. The proposed irrigation system combines a drip irrigation system, wireless sensor network, and wireless communication technology to develop a new irrigation modality. To implement this system, we present a new model based on the technique of monitoring soil parameters and weather properties in real time using a set of specific sensors. This model also improves remote decision-making techniques during irrigation by examining and analyzing measured data with threshold values of measured information.

4.1 Selected Technologies and Tools

We selected a group of tools and technologies to use in the proposed intelligent irrigation system.

- **Selection of Irrigation System:**

Irrigation is a process that allows to artificially bring of water to the soil, and thus to cultivated plants. The irrigation technique is mainly used in desiccated regions and covers inadequate or lack of rainwater.

Many irrigation systems currently exist and can be classified into three main categories:

- Surface irrigation (Walker, 1989): Includes any irrigation technique in which the application and distribution of water over the soil surface are made completely in the open air using gravity flow. It is the most common and oldest in the world. The use of rivers, deep tubular wells, and canals is observed in this type of irrigation.
- Sprinkler irrigation (Moreno-Jiménez et al., 2014): It is an imitation of rainfall phenomenon. It allows applying and distributing water on the soil surface as artificial rain. In this type, the water is distributed by a system of pipes under pressure then it is sprayed into the air through a set of sprinklers in the form of rain.
- Drip Irrigation (Dasberg and Or, 2013): It is a modern irrigation method that saves a lot of water compared to other irrigation systems. This method allows the distribution of water in the form of drops by allowing water to drip slowly to the root of the plant using a set of drippers distributed along the rows of crops. In drip irrigation, water is frequently applied for long periods of time at low doses, under low pressure, and at low flow.

In summary, surface irrigation consumes a significant amount of water compared to other irrigation systems. In addition, it is a technique with a low efficiency that always requires flat terrain or leveling. Sprinkler irrigation also consumes more water than drip irrigation. Moreover, this technique can be affected by weather conditions (e.g., wind can affect wetting patterns) and can promote the development of plant diseases. While drip irrigation has a range of features compared with other irrigation systems such as significant water saving, possibility of automation, and soil erosion limit. As a result, this technique is the most efficient and adaptable irrigation technique if it is well managed. Therefore, the choice of using drip irrigation is the best choice and may be advantageous in our proposed system compared to other irrigation systems (Pereira et al., 2002; Keeratiurai, 2013).

- **Wireless Sensor Network Technology:**

The wireless sensor network is a new technology that promises accurate monitoring and control of farmland at a lower cost. The self-organization of WSN which allows rapid deployment of the network, the transmission of collected data via intermediate nodes without increasing costs or energy, and the ability of network tracking by responding to specific application requirements (Ruiz-Garcia et al., 2009; Zhang and Zhang, 2012) are among the important benefits that make us choose to use wireless sensor network technology as a technique of coordination, planning, control, and monitoring in the proposed system.

- **Wireless Communication Technology:**

Various wireless communication technologies are involved in wireless sensor networks for effective communication of data. There are many technologies; the most commonly used are Wi-Fi, Bluetooth, and ZigBee.

- Wi-Fi (Kaushik, 2012): Wi-Fi technology was offered by the Wi-Fi Alliance (Wi-Fi Alliance Organization, 2018). It is a technology for Wireless Local Area Networks (WLANs) to connect wirelessly to the internet or to exchange information on the basis of IEEE 802.11 standards (IEEE 802.11, 802.11a/b/g/n).
- Bluetooth (Bisdikian, 2001): Bluetooth is a wireless communication technology based on radio frequency specification for short-range and inexpensive communication devices to replace cables and allows devices to wirelessly communicate with each other. Bluetooth technology depends on IEEE 802.15.1.
- ZigBee (Chook et al., 2007; Wang et al., 2016): ZigBee is a technology presented by the ZigBee Alliance (ZigBee Specifications, 2018). It is a specification based on IEEE 802.15.4 standard, defines a series of communication protocols used in the creation and design of a personal wireless network (WPAN) with low power radio signals. The technology specified by ZigBee is designed to be simpler, easier, less expensive, and with low flow.

From comparisons, referred in (Lee et al., 2007; Mihajlov and Bogdanoski, 2011; ur Rehman et al., 2014; Kumar and Ilango, 2018), between these different technologies, we find that ZigBee technology is the most effective technology in applications with low data rate and low power consumption, and therefore is more suitable for use in WSNs. Depending on our needs and our system, we can choose the use of ZigBee technology.

- **Choice of Sensors Used:**

Improving the performance and efficiency of irrigation systems depends on a combination of a variety of soil-related parameters and a set of weather parameters. Our proposed solution allows monitoring and measuring soil related parameters: soil temperature, soil moisture, and soil pH, and weather parameters: temperature, humidity, and wind speed. A range of sensors are used in this context (Thomasson et al., 2001; Kodali et al., 2014):

- Temperature sensor: It allows detecting and measuring the temperature. For example, soil temperature sensors make it possible to determine the type of crop, as well as provide alerts if the soil temperature exceeds a certain threshold.
- Soil moisture sensor: This sensor used to measure water stress level of the soil to indicate the quantum of effort required by the plant root system during the extraction of water from the soil. In the case where the effort required to extract water from the soil is greater, so the soil is drier.
- Wind speed sensor: It allows determining the speed of the surface wind. Winds on the surface of the Earth are turbulent and are characterized by random fluctuations of direction and speed. This type of sensor measures the wind speed value and transmits it as an electrical parameter.
- PH sensor: It measures the pH value (i.e., the pH is between 0 and 14 with pH less than 7 for the acids and pH more than 7 for the basics). In agriculture, values of soil pH situated outside the range of 5.5 to 6.5 and the soil pH value varies in the field, so it is helpful to apply the fertilizer according to the spatial variation of soil pH for support irrigation.

In order to implement the proposed solution, different sensors will be used such as Soil Temperature Sensor-ES1101, DS18B20 temperature sensor-Waterproof, EC-5 Soil Moisture Sensor, and Wind Sensor WM30.

4.2 Description of the Proposed System Design:

Figure 3 shows the proposed system, an intelligent system for management and control of irrigation deployed using a wireless sensor network. This system consists of several elements, including soil sensor nodes, weather sensor nodes, a range of different sensors (e.g., humidity sensors, temperature sensors, and wind speed sensors), base station, drip irrigation system (drippers, tubing, etc.), coordinator node, and electro-valve.

- Soil sensor node: It is a node that measures soil parameters (i.e., soil temperature, soil moisture, and pH in the soil). It includes a set of sensors (i.e., soil temperature sensor, soil moisture sensor, and pH sensor), microcontroller, transceiver, and battery for power supply. This type of node should be scattered on the soil in agricultural land. Each node routes the measured data from the sensors with a delay to a base station via wireless communication technology ZigBee.
- Weather sensor node: It is a node that measures weather parameters (i.e., air temperature, air humidity, and wind speed). It includes a transceiver, set of sensors (i.e., temperature sensors, humidity sensors, and wind speed sensors), microcontroller, and battery for the power supply. Each node routes the data that are measured by the sensors with a delay to a base station via ZigBee wireless communication technology.
- Base station: This is the entry point to the WSN. It allows the collection and analysis of detected and measured data from sensor nodes. Furthermore, the base station transmits the collected data through the internet or satellite to a coordinator node where a wider analysis of the measured and collected data can be performed.
- Coordinator node: A node that allows the identification and verification of the measured data by performing a broader analysis of these data. This node is used to send commands to other nodes. It also stores the collected and analyzed data in a database for easy viewing of the state of agricultural land to farmers, and thus facilitating decision making to activate irrigation or not.

Our system, intelligent irrigation system, is based on wireless sensor networks and drip irrigation. The procedures and steps of the proposed system are described and presented using the model of our proposed system (as shown in Fig. 3) and a series of steps describing the operation flow of this system (as shown in Fig. 4), as follows:

1. In the agricultural land, we disperse the soil sensor nodes and weather sensor nodes to configure a wireless sensor network.

2. Sensor nodes are used to provide an intelligent monitoring of soil parameters and weather parameters in real time. We use soil sensor nodes to measure soil parameters, i.e., soil temperature, soil moisture, and soil pH, using different sensors (mentioned above) and weather sensor nodes to measure weather parameters, i.e., air temperature, air humidity, and wind speed, using diverse sensors (listed above). The nodes are connected and communicated to each other through ZigBee wireless communication technology.
3. All measured and collected data by sensor nodes are sent via wireless communication for processing. Measured and collected data are routed via ZigBee to a base station. The base station collects, processes, and analyzes the measured data. Then it transmits these data to a coordinator node via internet or satellite. The coordinator node identifies and verifies these data by performing a broader analysis of these data.
4. Recording and backup of the processed data in a database are also performed.
5. Then based on the analysis of stored data in the database and the verification of these data with threshold values of each parameter measured, the needs of agricultural land and the amount of water needed for irrigation will be calculated and thus the irrigation decision will be taken.
6. In the case of dry soil, we will activate the drip irrigation system by pumping water to irrigate the crop. Therefore, an order will be sent to the system in order to open or close the electro-valve, and so to turn on or disable the drip irrigation system.

5 CONCLUSION AND FUTURE WORK

As a result of population growth and increased demand for food production, the automation of the agricultural sector has become very necessary and is in high demand. Therefore, the use of wireless sensor networks (WSNs) as a coordination technology in the various services of this sector, especially irrigation, generates a new exciting field for research that will develop and improve the efficiency of this sector, while increasing agricultural production and reducing the necessary costs. Our solution focused on the question of automated irrigation and proposed a new smart irrigation system using wireless sensor networks. In

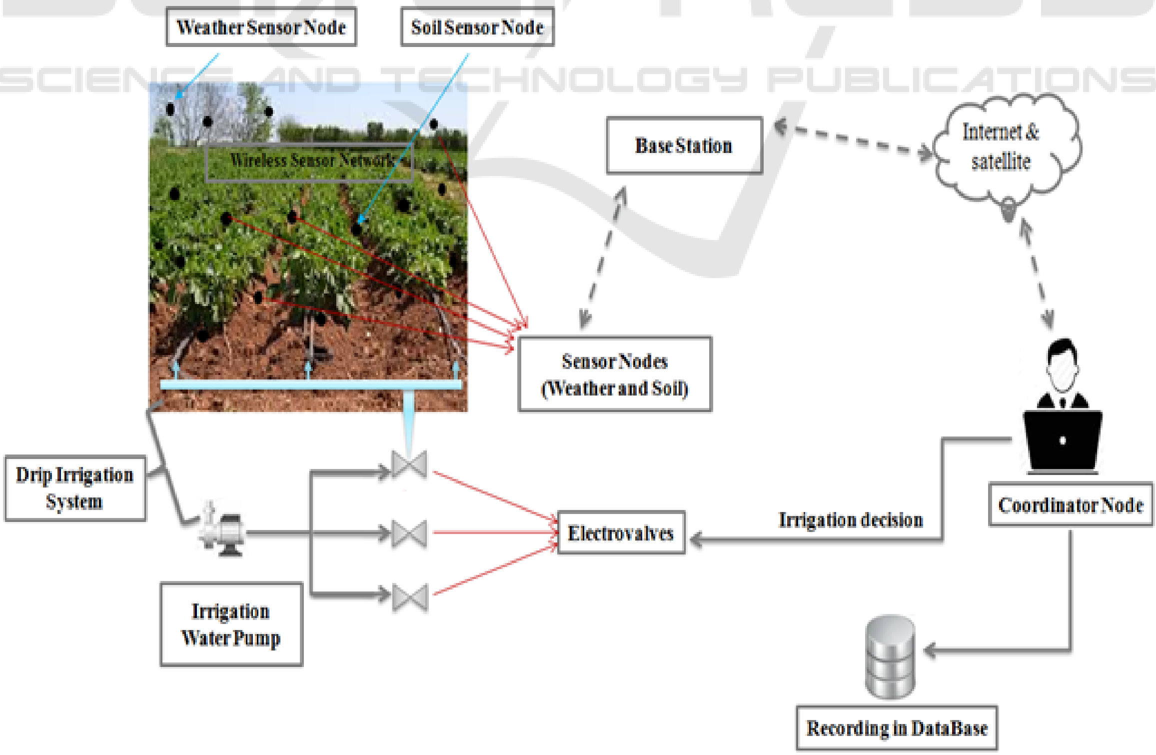

Figure 3: Intelligent irrigation system using WSNs (Proposed Model).

this paper, we presented and developed a complete and intelligent irrigation system based on wireless sensor networks and other modern technologies. Also, a detailed literature survey of different automated irrigation systems was presented. The proposed system relies on a model that monitors and controls soil and weather characteristics using a set of sensors deployed in agricultural land and improves making the decisions for the rational use of water in irrigation, and thus saving water, raising the performance of irrigation systems, reducing costs needed, and increasing the efficiency of production.

When the size of WSN increases (i.e., more sensors are added), the power consumption becomes very important, and thus the lifetime of the network is decreased. In future works, we will look for optimal solutions to minimize energy consumption. Also, we will approach the point of security where we will try to secure measured data using improved solutions of data encryption.

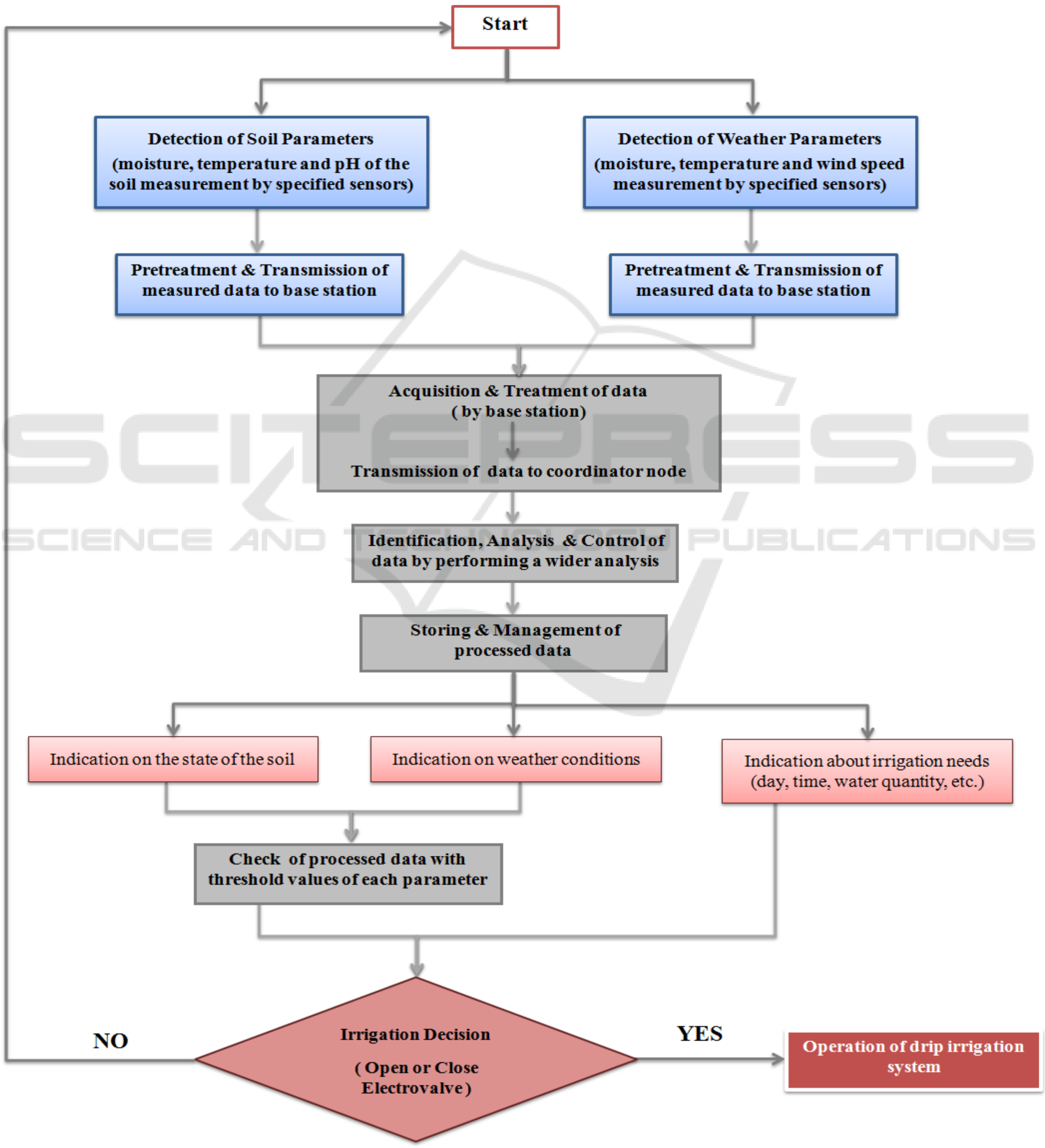

Figure 4: Workflow of proposed irrigation system.

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