Review on cyber-security for optimized and smart irrigation systems

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ABSTRACT

It is well known that the resources in agriculture are considered the most important factors for success. Therefore, numerous researchers are involved in the field of managing these resources, particularly water and consumed power. Moreover, the security side of these resources is considered, particularly the cyber-attacks. In this project, an optimized resource management method is proposed for allocating the available resources in a smart on-demand way. The proposed method is applied for dripped and sprinkler irrigation systems for managing the available water and generated power. In addition, an optimization method is utilized to obtain reliable solutions for managing the adopted resources. This method adopts a cyber security algorithm for preventing any possible attack. Wireless sensor network (WSN) is used as a reading source, in which the underlying area is covered well, since using sensors in irrigation systems is cost-effective that ensures on-demand irrigation process to save water and power resources. This network is supported by the fault tolerance method to increase availability.

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1. INTRODUCTION

Currently, different techniques are used in irrigation systems around the world as shown in Figure 1. Moreover, Table 1 illustrates the benefits and limitations associated with these methods. Therefore, developing an optimal irrigation system is necessary to reduce cost, power, and water consumption depending on real physical information instead of predicted one [1]. Nowadays, wireless sensor networks (WSN) have a significant role in many applications, such as environmental monitoring, medical, agricultural, and others due to their flexibility and ability of processing data in different environments with easy programming [2]-[4]. The use of sensors in recent applications is not limited to environmental sensing, collecting data from the field, and sending information to users depending on some situations [5], [6]. Power resources in sensor nodes are batteries that have a limited lifetime and difficulty in replacing or recharging them. Thus, it is important to design an optimal power consumption network to increase WSN life [7]-[10]. Moreover, irrigation in agriculture consumes about 85% of the total consumed water in the world and this will increase rapidly with the increase in population, therefore it is important to design an irrigation system with optimized use of water resources [11]-[13].

At the other hand, security and cyber-security are important aspects to be considered in developing smart systems with WSN [14], [15], because sensor nodes are used to collect specific and critical information to be sent to an appropriate destination to take a decision. Therefore, the existence of a malicious node in the network of irrigation system can lead to send a fault decision to the actuators resulting in wasting water and harming crops [16]. Obviously, denial of service (DoS) attacks are the most notable attacks in the field of availability that prohibit clients from receiving the specific data with the right time [17]-[19]. In addition, the use of WSN for systems decision making requires the reliability, availability and confidentiality which can be achieved using fault tolerance methods in software engineering [20]. In this paper, an optimal, secured and reliable smart irrigation system based on WSN is produced in the literature to manage the resources in irrigation in optimal way.

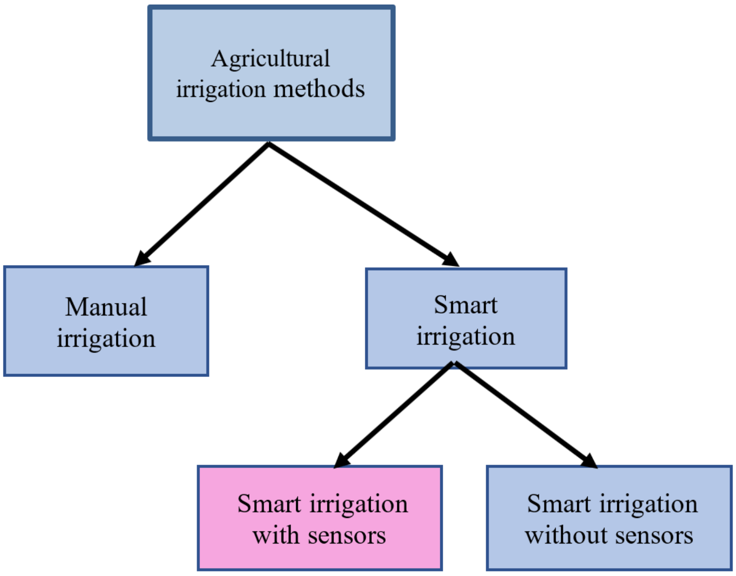

Figure 1. Agricultural irrigation methods [1]

Table 1. Advantages and limitations of irrigation methods [1]

Irrigation kinds	Advantages	Limitations	Implement
Manual irrigation	– Less resource – Lower cost	– Wastage of water, – Dependency on resources, – Not recommended due to lack of resources	Currently is used
Smart irrigation	– Less resource – Effective – Environmentally – Friendly	Costlier one (depends on the particular functionality)	Not widely used due to lack of technical exposure
Sensor dependent	– Unique concept – For irrigation – Long life – No harmful effects – Portable – Easy to deploy – Cost-effective	No as of now	Can be used in any location
Sensor independent	– Not efficient as compared to sensor-based repellent – Not highly effective	All the drawbacks of manual irrigation come under this	

2. SYSTEMATIC LITERATURE REVIEW

In order to cover the recent research work regarding the subject of smart irrigation systems, a systematic literature review protocol is considered to produce this paper with different manuscripts. The preferred reporting items for systematic reviews (PRISMA) methodology is used in this search , which is a framework developed to depict the flow of information through the different phases of a systematic review [21]. Figure 2 explains the adopted resource and the PRISMA for this paper. This section can be classified depending on the function of the included manuscripts in literature as:

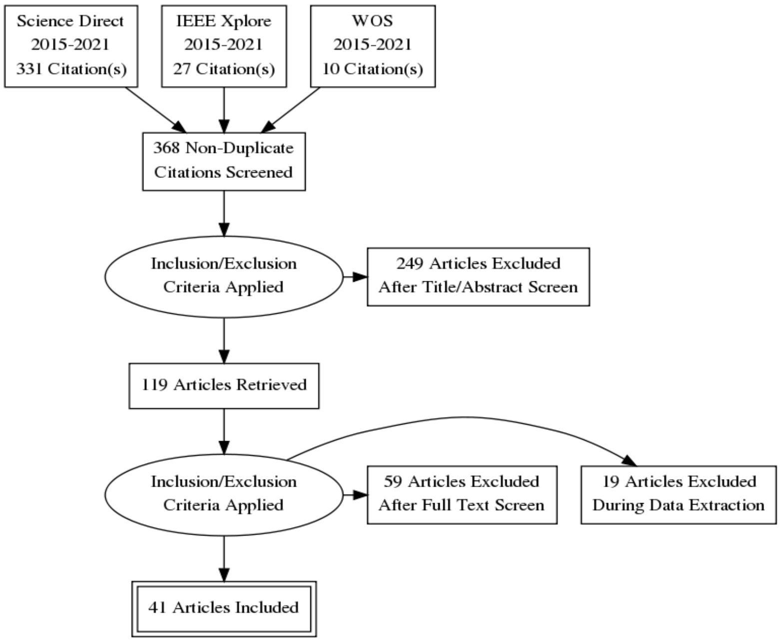

Figure 2. PRISMA flowchart of the adopted systematic review

2.1. Smart irrigation system based on WSN

As mentioned earlier, depending on the functionality of the reviewed papers, 30 articles proposed a smart irrigation system based on WSN to monitor and control irrigation process. In [22], an internet of things (IoT) based smart agrotech system was proposed to improve farm production using efficient monitoring and scheduling irrigation process. The collected data from sensors (soil moisture, temperature, and humidity) compared with real data using comparative analysis and results showed an acceptable error on the charge of lacking in coverage area. While in Liao *et al*. [23] developed a smart drip irrigation system depending on real-time soil moisture data in a greenhouse tomato's crop. A comparative study between the proposed system and other irrigation systems was done with results approved that the giving system is efficient to deal with food security and water scarcity issues. Abioye *et al.* [24] presented an efficient monitoring and data-driven modelling of the information influencing the irrigation of mustard leaf plant. At the other hand, Torres *et al.* [25] submitted a multilevel data fusion architecture to get an accurate sensor readings that lead to accurate decision making. Three categories were involved in the proposed architecture: sensor data fusion, event and decision making, and decision fusion based on multiple applications. In [26], a smart agriculture system was developed with an open source and not expensive hardware components like built a WSN using Arduino and Raspberry Pi to get a cost-effective system. The fuzzy logic control was used as a decision method for the amount and duration of irrigation. An automated irrigation system based on IoT was presented in [27]. This was done by distributing different sensors in the farm (soil moisture, temperature and humidity) and the reads are entered to a machine learning algorithm. Sodhi and Saxena [1] proposed a smart irrigation system based on microcontroller and used Bayesian analysis hosted on IBM Waston platform to monitor the health of the crop, the required water to irrigation and every detected intrusion. The water pumps are activated automatically when the soil moisture level (measured by sensor nodes in WSN) is less than a threshold value. Intelligent agent concept was used in [28] to design and implement a cyber-physical irrigation system. The physical data collected using WSN and a weather station while processing of these data is done in a central station to decide the irrigation status based on these data. At last, a control signal is sent to the actuator system by the intelligent agent to power on the solenoid valves for starting irrigation. Ali *et al.* [29] and Tiglao *et al.* [30] considered the use of IoT and mesh WSN in designing an irrigation system. Jaiswal and Ballal [31] proposed an automated drip irrigation system using real-time fuzzy inference method and WSN implemented in LabVIEW. In [32], a monitoring and control irrigation system was proposed based on multi agent system. The WSN gathered data from environment to evaluate the actual need of water every five minutes and weather map used to calculate the potential evapotranspiration precisely. Karunanithy and Velusamy [33] presented an automated drip irrigation with fertigation system based on WSN. The proposed system utilizes soil moisture data and evapotranspiration for prediction of required water to irrigate the area. This system proposed also a transmission method between cluster head and a base station based on travelling salesman protocol (TSP) to reduce power consumption in data transmission. results approved that the proposed system used water efficiently.

The irrigation system proposed in [34] used dynamic sensor data and real time weather information and static data like plant and soil type to decide the irrigation process. artificial intelligent (AI) algorithms have been used for training and testing data. Barkunan *et al.* [35] suggested an automated irrigation system based on sensing rain fall in a farm. The information is transmitted using global systems for mobile/general packet radio service GSM/GPRS technology to the farmers at anytime and anywhere to check the status of the farm. In [36], a developed real-time agriculture application was presented using multi-layered architecture containing three technologies (internet of things, cloud computing and context awareness). In [37], a smart irrigation system based on WSN and fuzzy logic was suggested. A comparison was made between a crop irrigated with traditional irrigation and with proposed system showed that the proposed system used quantity of water equals to half the required quantity using traditional method. Nawandar and Satpute [38] proposed a smart irrigation system with low-cost target using IoT platform to collect data, neural network to make decisions for scheduling irrigation depending on the collected data and the user viewed the data remotely using message queuing telemetry transport (MQTT) and hypertext transfer protocol (HTTP) protocols. This system is intelligent, cost effective and portable.

At the other hand, the smart drip irrigation system proposed in [39] used smartphone to capture soil image. Calculations were made on the image to know the level of wetness and send the data to a microcontroller to take an irrigation decision depending on the captured image in smartphone and sensors output. Muangprathub *et al.* [40] proposed a control system to control environmental parameters that affect the crop production. Three parts included in the control system: hardware component, web application and mobile application. In [41], a low cost smart irrigation system based on IoT and weather was developed to control irrigation process automatically depending on moisture level value. While in [42], agricultural physical system (ACPS) with solar irrigation facility was proposed to manage irrigation process remotely. Photovoltaic energy was used as a power source in the proposed system and client-server architecture used to ensure communication in two directions between the executional level in the field WSN and managerial level in the cloud.

Selmani *et al.* [43] presented a solar photovoltaic watering system (SPVWS) with multithreading design and virtual timers. Raspberry pi was used due to its efficient performance with real time applications. By multithreading programming used in the system, controlling the system and HTTP server job working concurrently to give remote control of the irrigation system and online monitoring of data. The proposed system in [44] used IoT to automate controlling and monitoring of irrigation process. Sensor devices collected environmental data from the field and regression algorithm used this data to determine water requirements in a day. Mohapatra and Lenka [45] proposed a watering system with future prediction of soil moisture content using neural network. The expectation strategy utilized the collected data from sensors such as soil and weather parameters. In [46], an irrigation management system based on WSN was developed to automate irrigation process. Sensors gathered data from field and sent it to the controller for irrigation decision and to the server for monitoring purpose. Khelifa *et al.* [13] proposed an automated irrigation system based on WSN to gather data for irrigation process decision. A web application in smartphones also used to give notifications when the soil is dry or the level of the water in the tank is low. The WSN connected with the server using 4G-LTE technology due to its flexibility. In [47], a smart irrigation system is proposed to control and monitor irrigation process using WSN and fuzzy logic as a decision tool. Sensor nodes collected data from a field, decision support system used this data to schedule irrigation using fuzzy logic methods and actuators to execute commands. Abdullah *et al.* [48] presented a simulation model to a smart irrigation system based on WSN. In the proposed model, WSN used cluster topology to ensure a scalable network and increase sensors life time. The proposed system used fuzzy inference system to irrigation control. Simulation results showed that the system performance is accurate with economical use of water and power. In [49] a wireless sensor/actuator network (WSAN) with an adaptable decision support system was integrated to get an automatic irrigation system. To analyze data, a machine learning process had been used to get new knowledge. To ensure that the developed system is effective, the performance of the system was compared with classical agricultural exercises.

2.2. Optimization with smart irrigation system

The systematic literature review protocol includes seven research articles that deal with optimization problem in irrigation system based on WSN. In [50], a reliable low-cost information gathering protocol (RLCIG) was proposed for irrigation system with WSN. Clustering techniques were used for data aggregation with optimized power to increase network life. For balanced clustering, conditional spider optimization (CSO) algorithm was used, while for optimal path selection, the system proposed using flower-bee search (FBS) algorithm. The proposed method was tested using simulation and the results show an improvement in transmission range, cost and system lifetime. Briones *et al.* [51] suggested a new multi-agent system (MAS) to get an automated monitoring and controlled irrigation system for potato crops. MAS was developed using a cloud computing platform which can collect information from WSNs to define factors and determine irrigation requirements.

This smart system has the potential to keep resources and upgrade the efficiency of crop production systems, specially in rustic areas. The intelligent irrigation system presented in [52] was developed to decrease water consumption by combining IoT, cloud computing, and optimization techniques. The used optimization model minimizes the consumed water efficiently. The efficiency of the suggested approach, which minimizes irrigation water use, was proven by a comparison of the recommended optimization-based control model with the flow-based control model

Ocampo and Dadios [53], a multi-objective optimization method using an intelligent irrigation system was introduced to reduce the energy cost of operating two water pumps that maintain the water required for farm's irrigation. It was significant to obsereve that the genetic algorithm was used to get the optimal solution. To achieve optimal water consumption, the authors of [54] suggested integrating the automated irrigation system with an accumulative neural network (ANN). The suggested system was simulated using the MATLAB Toolbox of neural network with feed-forward backpropagation ANN model. In addition, in Maurya and Jain [55], suggested an approach for designing WSN-based automated irrigation systems. All sensor nodes collect data on an ongoing basis. However, just data with a recurrent timer is sent to the base station or data that exceeds the threshold. To reduce the node's power consumption for each transmission, fuzzy logic was utilized to locate the entire cluster head in the existing round. Comparisons with other routing protocols have shown that it effectively minimizes power consumption at each transmission and extends the life of the entire network. In [56], a WSN-based intelligent irrigation system with optimal consumed power using the Lagrange multiplier method was suggested. The aim was to partition power optimally and efficiently, while optimally minimizing power and watering, depending on the plant's watering needs and watering time.

2.3. Cyber-security with smart irrigation system

As the security is important aspect in the field of information systems including irrigation, different researchers tackled this issue. While in cyber-security side, there is a smaller number of research work due to new entrance of irrigation field. In [57], a smart irrigation system was proposed with the assistance of an android application. Variety of sensors, soil moisture, air humidity, and air temperature were used to collect physical information. Once the data reached the server, a fuzzy logic control was used for take decisions depending on the required irrigation. The block chains were used to provide the required reliability in the smart system by limiting the access and control of the suggested system to only authorized devises. The system was efficient for handling the irrigation process securely. Saleem *et al.* [16] proposed a data encryption method to ensure the accuracy of collected information by WSN to get an effective irrigation decision. The encryption mechanism had been inspired by blood brain barrier (BBB) system to ensure efficient data transmission in WSNs. The system was simulated using network simulator two (NS2) and the results approved the efficiency of the proposed encryption method in protecting data communication from various attacks.

2.4. Fault tolerance with smart irrigation system

As the irrigation systems are considered as important parts of feeding security around the world, it is necessary to ensure the reliability and availability of them through using fault tolerance techniques. Some researchers adopted the presenting of solutions to this aspect in the literature. Ramli *et al.* [58] suggested an adaptive technique to achieve reliability in a smart farm using two network protocols: LoRaWAN and IEEE 802.11ac in a smart monitoring system. The sensor data has a small data size with low energy, so LoRaWAN protocol is suitable for transmitting it. Moreover, transmitting video data was done using IEEE 802.11ac that had a higher data rate. Using two network protocols helped in getting a reliable monitoring system in comparison of using a single protocol technique. In [59], a novel approach for the recovery from simultaneous failures was proposed for a large-scale multi-channel WSNs called simultaneous failure recovery based on relay node relocation (SFR-RNR). As a case study, the authors chose precision agriculture application because it had thousands of thousands of sensors. The proposed approach aim was to rebuilt the connection and the network coverage after failures.

3. PROSPECTIVE SOLUTION METHODOLOGY

As mentioned in the reviewed papers of [1]-[59], the problem of managing the resources (water and power) in the irrigation systems has been tackled in different directions that dealt with security, optimization, WSN management, or fault tolerance individually. Therefore, there is a real need for finding a solution methodology for finding a comprehensive scheme that manages the irrigation systems. This scheme aims to propose a smart irrigation system (dripped and sprinkler) that adopts a developed optimization, cyber-security, fault tolerance methods. This is to present a comprehensive irrigation system that can manage the available resource of water and power to achieve the aspects of reliability, availability and confidentially. A diagram in Figure 3 shows the structure of the proposed project based on the results of the systematic review.

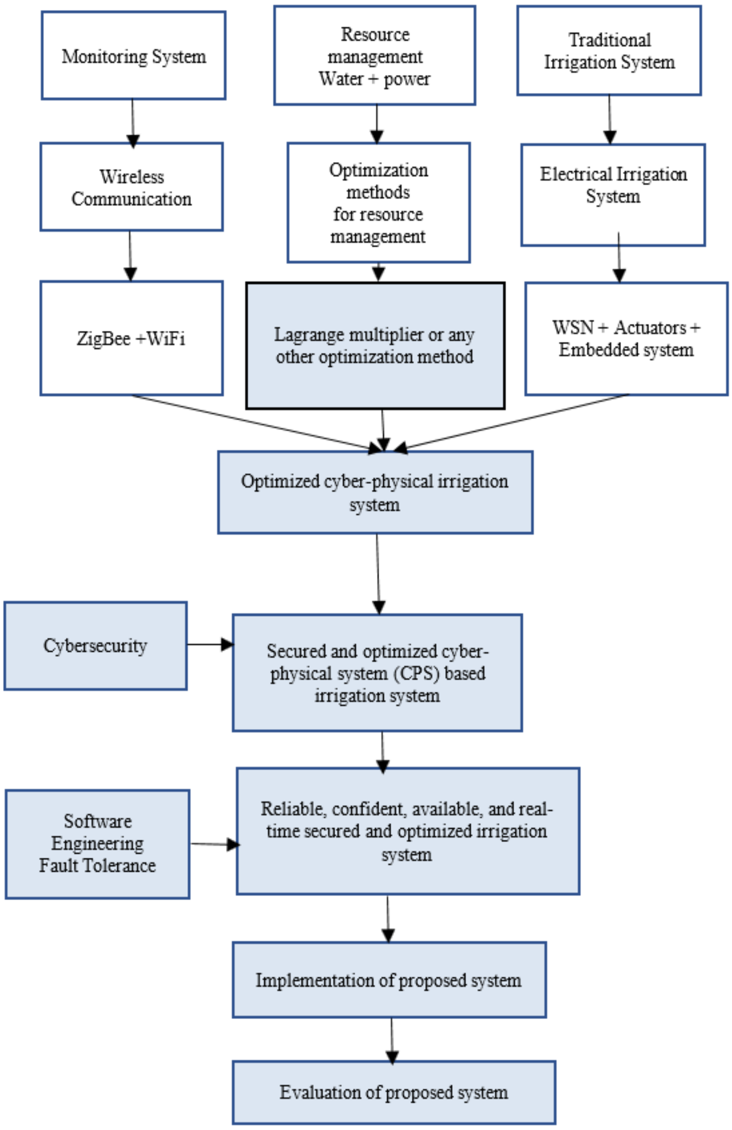

Figure 3. Structure diagram of the presented solution methodology

The highlighted boxes in Figure 3 shows the suggestion solution methodology, considered as contributions. These contributions are the results of the systematic review that sorts the problems as a heretical from bottom to top. Ideas can be summarized as:

1) Designing and implementing of smart dripped and sprinkler irrigation system based on clustered WSN. The designed WSN is based on:
   – Nodes of sensors and a base-station for each cluster.
   – Irrigation systems that include water pumps and actuators.
   – The MQTT protocol is adopted in managing the data transmission in the WSN as well as part of security in terms of authentication.
2) Producing an optimized method for managing the consumed water and power to be reduced efficiently. This method can take care from availability of the proposed system. The possible optimization methods that can be adopted include but not limited to swarm intelligent, ANN, gentic, fuzzy logic and Lagrange multiplier. These methods are multi-objective methods and based on finding-out the optimal balancing factors in the mathematical model of the proposed system.
3) Introducing a cyber-security algorithm for detecting and tracking the DoS attacks that can be occurred in the proposed management method and the whole irrigation system. This algorithm guarantees the confidentiality and availability of the presented system. It includes two phases:
   – Physical phase: it implemented in the WSN level to protect the data transmission between the nodes, irrigation bumps and base-stations.

– Server phase: it is used to protect the server itself and the data transmission between the server and base-stations.

4) Adopting a fault tolerance-based monitoring method for the proposed system to solve the problems of occurred faults in terms of hardware and software. This method can guarantee the availability and reliability of the proposed system.

Figure 4 shows the suggested system block diagram that explains the levels of hardware and software that are considered for solving the mentioned problems in managing power and water resources of irrigation systems. This system can be briefly explained as: 1) sensor nodes and water bumps are connected to a base-station to build a cluster in WSN. The base-station is responsible of controlling irrigation process by sending power on and off commands to water pumps with proper irrigation time depending on sensor's readings and climatic conditions. Moreover, the base-station and related nodes as well as bumps apply the introduced cyber-security, water and power optimization, fault tolerance and normal data transmission methods; and 2) clusters of the WSN are connected to the server throughout their base-stations with authentication protocols to monitor irrigation process as well as building data bases to the proposed irrigation system. The server applies cyber-security, data saving in the built database, fault tolerance, and normal data transmission.

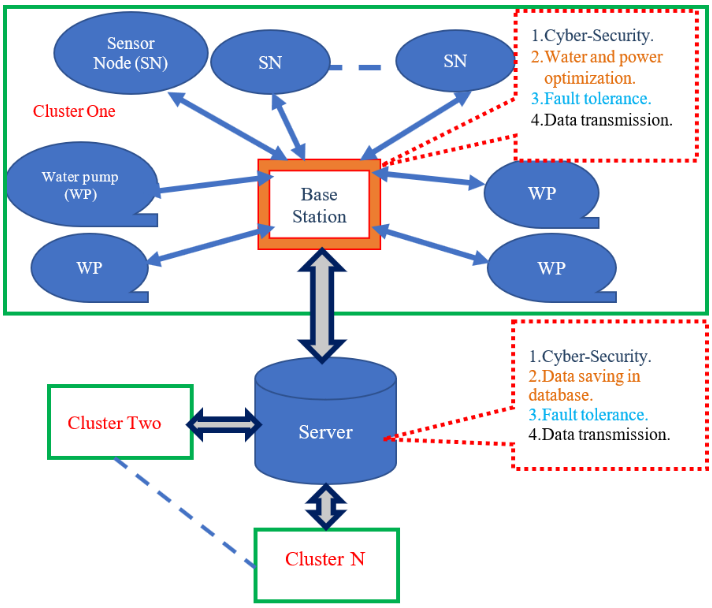

Figure 4. Suggested system block diagram

4. CONCLUSION

A systematic literature reviews on the previous researches about smart irrigation systems was presented in this paper to stand on their limitations and propose solution methodology in terms of reliability, optimization and cyber-secured smart irrigation system based on WSNs. The systematic literature review showed that the research work considered each side of problems in individual way. Therefore, the need for producing a comprehensive management system for smart irrigation based on WSN. The solution methodology for covering the drawbacks of the research work in literature was introduced a block diagram with description about its contributions to enhance the current irrigation systems have been produced. The results of the suggested system are expected to show a high performance in terms of reliability, availability, and security.

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