International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys.14, No.1 (Oct-23)

http://dx.doi.org/10.12785/ijcds/1401104

The Recent Technological Trends of Smart Irrigation Systems in Smart Farming: A Review

Roufaida Khebbache[1], Abdelhak Merizig[1], Khaled Rezeg[1] and Jaime Lloret[2]

[1]*LINFI Laboratory, Computer Science Departement, Mohamed Khider University of Biskra, 07000, Biskra, Algeria*
[2]*Instituto de Investigación para la Gestión Integrada de Zonas Costeras, Universitat Politècnica de València, 46730 Grau de Gandia, Spain*

Received 28 Apr. 2023, Revised 17 Aug. 2023, Accepted 10 Sep. 2023, Published 1 Oct. 2023

Abstract: Agriculture is considered one of the most vital industries worldwide responsible for people's food and the country's economic development. Nevertheless, this sector is the largest consumer of freshwater. Access to water, soil kind, weather conditions, fertilizers, and illnesses are crucial aspects of agricultural activities. Moreover, water scarcity has become a significant issue for farmers to tackle irrigation activity. While irrigation depends on water availability, building smart irrigation systems that control and manage water use efficiency is highly needed. This paper examines the most modern technologies used in irrigation systems over the last few years. This survey can easily be thorough and beneficial to academics while providing essential recommendations for the new era of irrigation systems technologies. The findings indicate widespread use of the Internet of Things (IoT) and artificial intelligence algorithms, while digital twins and blockchain technologies are less common and still in the early stages. To reduce costs and improve security in irrigation systems, it is strongly recommended to adopt digital twin technology. By utilizing digital twins, farmers can enhance operations, optimize resource utilization, and increase efficiency. Furthermore, digital twins contribute to identifying vulnerabilities and implementing robust security measures, ensuring protection against potential threats and disruptions.

Keywords: Agriculture 4.0, Smart agriculture, Smart irrigation, Digital twin, IoT, Artificial intelligence.

1. INTRODUCTION

Global food security is threatened by several issues, such as climate change and resource degradation. The impact of climate change, mainly changes in rainfall patterns, on agricultural productivity is a crucial determinant of food security for the population [1][2]. As the population increases, water is required for various purposes, including irrigation, residential, hydroelectric, industrial, etc. [3]. The agriculture sector is the largest water user, which requires a large portion of a country's water resources. In fact, there exist several irrigation methods, including rain-fed irrigation, subsurface (drip/sprinkler/mist), and micro-irrigation, gradually replacing surface or flood irrigation. These methods have the intrinsic capacity to double the land under irrigation without sacrificing agri-output [4][5]. The conventional irrigation systems could have been more efficient in terms of water use, resulting in excessive waste of this resource and challenges and problems in the soil of many areas due to extensive waterlogging and salinity [5][6].

On the other hand, irrigation systems are inefficient runoff, wind, and evaporation waste almost half of all irrigation water. For planning, most traditional irrigation systems employ basic timers and controllers. As a result, effective water management is critical to long-term productivity increases; thus, using water only when needed and in exact proportions is a significantly more efficient method [7][8]. Micro-irrigation and smart irrigation employing wireless sensor networks are advanced irrigation systems that boost water use efficiency and productivity without damaging soil health [9][10]. The Agricultural field, like many other areas, incorporated Internet of Things technologies. Farmers have been helped in various ways by using Internet of Things technologies in different agriculture activities [11]. The Internet of Things helps agricultural management by enabling farmers to maximize efficiency through resource management [12].

The irrigation phase of the agricultural cycle is critical. A suitable amount of water is required for plant growth. Irrigation is used to provide additional water to plants when rainfall is low [13]. Most irrigation is done from one end to the other using traditional stream flows and other old techniques. Usually, they rely on water supplies, which take time and waste water resources [14]. Since the machine

E-mail address: roufaida.khebbache@univ-biskra.dz, a.merizig@univ-biskra.dz, k.rezeg@univ-biskra.dz, jlloret@dcom.upv.es

revolution and ICT technology (agriculture 4.0), innovations and technologies, including artificial intelligence (AI), digital twins, the internet of things (IoT), and unmanned aerial vehicles (UAVs), have substantially reduced farmers' hard labor work, allowing agribusinesses to boost profits and save time when compared to traditional farming methods. Moreover, it supports maintaining and enhancing soil quality and ensuring optimum water utilization and irrigation control [15]. Actually, the high spread of IoT technologies that covers almost all areas of our daily lives, including agriculture, will be significantly affected by the advancement of IoT technologies in the coming years. There is an anticipation that it will have an even more significant influence on more areas in the coming years.

Besides the systems for irrigation and fertilization, there are also practices such as monitoring the weather, examining the soil, controlling diseases and pests, and more, where the IoT has significantly contributed to these areas. AI techniques aim to emulate biological activity while also taking into account how the human brain makes decisions. Artificial intelligence related technologies offer interesting irrigation automation possibilities [16].

According to the published literature review, most works focused on irrigation system hardware or conventional irrigation methods. However, only some of them presented irrigation system technologies. We have taken this into account as the primary interest of this work. We intend to review the recent technologies in the irrigation field during the last few years and determine the specific technologies and techniques employed by various irrigation systems to help searchers. This study will help respond to the following research questions (RQ):

1) What is the best way to deal with water waste, and can farmers regulate irrigation water?
2) What are the technologies used in irrigation systems?
3) What are the appropriate water sources for specific crops?
4) Did irrigation operation costs mentioned in these works?
5) What are the recommendations for IoT-based irrigation applications and challenges related to using intelligent technologies in irrigation systems?
6) What are the techniques that handle generated data in irrigation systems?

Our research questions cover the following drawbacks:

- Water scarcity for its distribution, especially in the agricultural field.
- An increase in the number of sensors installed in the field will affect the general fee.
- The high cost of time processing.
- Issues with missing data during the data collection and streaming processes.
- Data security needs to be carried out during the data collection and transfer.

A. Motivation and Contribution

The interest in irrigation-related technology prompted a review of the literature, and the findings of the review are reported in this article. The motivation behind the present comprehensive study is to review the most critical enabling technologies in the irrigation field applied to smart farming in recent years and over the next few years.

Due to gaps in the findings of the literature, most studies have focused on presenting machine learning algorithms or IoT-based hardware in this field, although the use of digital twins as well as blockchain, besides IoT and machine learning, has rarely been mentioned. Furthermore, neither water distribution nor water resources, the cost of hardware, nor security challenges have been mentioned. These gaps have been addressed in this research to provide necessary answers while helping farmers and researchers gain insight into the vital cutting-edge technologies in the irrigation field.

A search was performed based on keywords for articles published in relevant journals or conferences to conduct the review's bibliographic analysis. The search was carried out between the years 2020 and 2023.

For this review, we selected scientific research databases such as IEEE Xplore and ScienceDirect, along with the scientific search engine Google Scholar. A total of more than 60 papers were examined. In this paper review, the analyzed journal articles and conference papers are illustrated in Figure 1. The essential contributions of this study are listed below. In this work, we combine the crucial enabling technologies that have a vital impact on the agriculture industry, both presently and in the future. Implementing these technologies on a large-scale farming basis is expected to bring changes to the agriculture industry and commerce.

In addition, we outline enabling approaches integrated with IoT technology and describe the essential components of these techniques in irrigation agriculture. Furthermore, we carry out smart farming applications that use digital twin technology.

This technique is operated from a technological standpoint, which is significant only of interest and value to employees in the area but also from an agricultural standpoint, noting all of the major factors in this research field. Finally, we examined the major problems and new opportunities for promoting sustainable irrigation water use in agriculture.

The remainder of this paper is structured in the following manner: Section 3 explains the background of using technologies. Section 4 describes the literature survey. Where Section 5 discusses the crucial challenges and opportunities. Section 6 presents the discussion of the works. To end up, Section 7 concludes the paper with the future work.

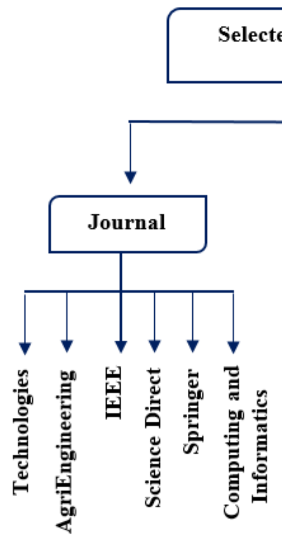

Figure 1. Journal articles and conference papers that were analyzed

2. Methodology

To investigate the research questions outlined in the Introduction, we conducted a literature survey within a specific timeframe, taking into account the emergence of recent phenomena like the Internet of Things, Blockchain, artificial intelligence algorithms, and digital twins. The choice of this timeframe was based on practical considerations. In addition to considering the publication period, we applied inclusion criteria during the literature search to ensure the relevance of the sources to our research questions.

The literature survey followed a systematic approach consisting of three steps. Initially, we conducted searches in two major bibliographic databases, namely Web of Science and Scopus, using different combinations of two sets of keywords. The first set included terms related to IoT, artificial intelligence algorithms, blockchain, and digital twins (e.g., Artificial intelligence algorithms, data-driven systems, blockchain technology, Internet of Things, IoT, digital twins), while the second set focused on smart irrigation (e.g., agriculture, farming, precision irrigation, irrigation systems). From these databases, we retrieved more than 60 articles, which were then evaluated for relevance by identifying passages that addressed our research questions. Consequently, we considered 20 articles as the most relevant and 44 articles as relevant to our study.

In the second step, we thoroughly examined the selected literature to extract information that was pertinent to our research questions. Finally, in the third step, we analyzed and synthesized the extracted information, following the conceptual diagram described in Figure 1.

3. Background

The agricultural sector has undergone a revolution with the widespread adoption of information and communication technologies (ICT), including the Internet of Things (IoT), artificial intelligence (AI) algorithms, digital twins, and blockchain. These technologies have been successfully implemented in various areas of agriculture, bringing about significant advancements and improvements.

A. Internet of Things

The Internet of Things (IoT) is a concept that combines different technologies and a vast array of physical objects or items, including but not limited to RFID tags, sensors, actuators, mobile devices, and more. By using unique addressing schemes, these latter can collaborate with their neighbors to accomplish shared objectives [17][18]. As depicted in figure 2, the Internet of Things (IoT) is used in several domains like agriculture, healthcare, military, economics, and transportation.

Figure 2. Application domains of the Internet of things.

In recent years, the Internet of Things (IoT) has been widely utilized in various domains, as previously mentioned. In agriculture, IoT devices have demonstrated remarkable efficiency and offer numerous advantages, including:

- Controlling irrigation processes.
- Monitoring soil moisture levels for better resource management.
- IoT sensors assist farmers in collecting essential environmental data, leading to effective farm management (see Figure 3).

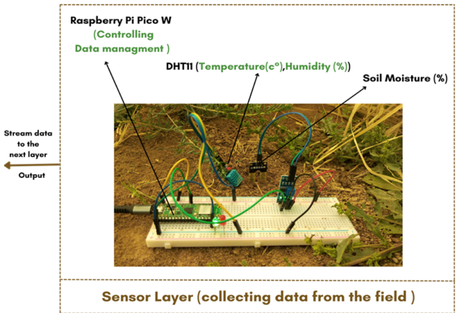

Figure 3. Different IoT sensors and devices.

Numerous researchers have referenced it in the irrigation stage of the agricultural life cycle. [19] suggested an approach that uses a hybrid cryptographic algorithm that incorporates Rivest cypher (RC4), Elliptic-Curve Cryptography (ECC), and Secure Hash Algorithm (SHA-256). Additionally, the SHA-256 algorithm safeguards sensitive information in IoT of innovative irrigation and enhances the security of the Internet of Things using cryptographic algorithms. The proposal discusses a case regarding innovative irrigation systems named SpringerLinkgation systems.

[20] have proposed an architecture for the water system, where the techniques are cloud computing and the Internet of Things (web of things). A range of sensors was utilized to gather continuous data on the water system; after that, the data was stored in the cloud, the owner of the data delivered the order, and the right move was made depending on the outcome created.

1) Wireless sensor networks (WSN)

A WSN network comprises some sensor nodes (ranging from a few tens to thousands); these nodes operate together to monitor and collect data about an area. There are two categories: structured and unstructured WSN [21]

1) An unstructured WSN is a sensor network that consists of a large number of nodes. Sensor nodes can be placed in the field on an ad hoc basis. Once the network has been installed, it is left unsupervised to perform monitoring and reporting tasks. Managing network maintenance, which includes tasks like connectivity management and fault detection, is difficult because of the large number of nodes involved.
2) All or some of The sensor nodes in a structured WSNs network is deployed in a predetermined order. Reducing the number of nodes can lead to lower costs associated with network maintenance and administration. These nodes are located in particular regions or designated locations and the Deploying nodes strategically ensure coverage, whereas ad hoc deployment may result in areas with no coverage.

In the agricultural sector, WSN sensor technology, with a network of sensors, is employed for precision agriculture as shown in Figure 4 that offers different benefits including [22].

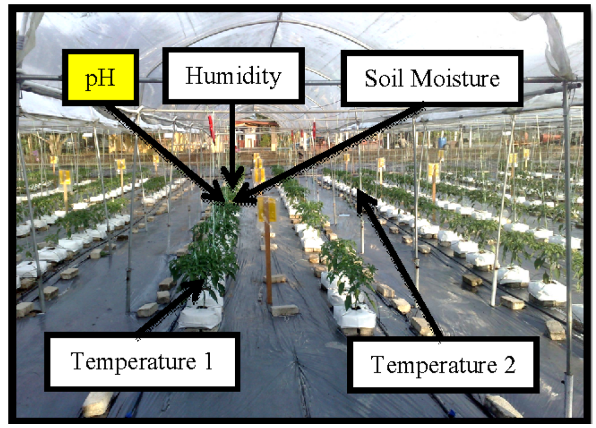

Figure 4. Typical WSN for calculating different parameters.

- Monitoring the level of water, the proper placement, and the appropriate time to begin growing crops.
- A WSN has the extra benefit of consuming less power and providing more precise results.
- Implementing WSNs in agriculture increases the output of high quality crops while decreasing the yield of low quality crops.
- Instant alarms are generated when trespassers or rats come into contact with planted crops.
- WSNs eliminate the need for frequent human intervention and minimize the frequency of human errors.
- Via a smartphone connected to the WSN, agricultural statistics can be accessed [23].

Many researchers developed agriculture applications using WSN, we cited [24], who have proposed a system that simulates the demand for crop water, with a sensor that calculates the groundwater level, the data collected, and a wireless sensor network has been used. The system includes a Web-based dashboard for decision-making to capture real-time data on crop water demand, irrigation scheduling, and groundwater discharge and recharge.

As part of a more extensive study of this crop's genetic responses to drought stress, [25] have developed a sensory control system for wheat to simulate drought conditions. A drip irrigation technique was applied to maintain the soil moisture on potted wheat plants within a specified range. Additionally, it provides biological studies better to understand drought stress's effects on wheat growth and predict the amount of water required for irrigation at different phases of wheat growth.

2) Cloud computing

We can define Cloud Computing as a notion that provides network access on-demand to a collaborative collection of resources that is capable of being adjusted or customized to fit specific requirements, such as (networks, servers, storage, applications, and services). Furthermore, The cloud can be rapidly provided and installed using minimal administration work or interaction with a service provider. IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS are the three categories of cloud computing (Software as a Service) [26][27][28].

In agriculture, several applications were made while providing distinct advantages, as shown in Figure 5.

- Cloud-based Fertilization system.
- Insects and pest detection. The collected data is stored in the cloud for further analysis.
- Weather forecasting for crop management.
- Land sustainability prediction.

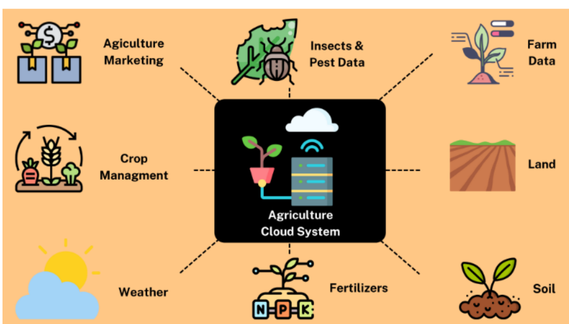

Figure 5. The new age of cloud computing in agriculture.

[29] proposed an intelligent irrigation system that focused on weather forecasting. The system used different technologies like AI, which is done with the Wind-Driven Optimization - Least Square Support Vector Machine (WDO-LS-SVM) algorithm and a Long-Range Wide Area Network (Lora WAN) communication link.

[30] offered a cloud-based software program integrated with IoT devices. The system is capable of automatically setting irrigation schedules. By making employing sensor technology to gather environmental data from the field and consulting with agricultural specialists, the system can establish irrigation schedules. Furthermore, another advantage is that expanding the application to include fertilization and offering weed and pest management advice could be done effortlessly.

3) Intelligent agents

The software components known as intelligent agents can cooperate and work with other agents in multi-agent systems (MAS). To automatically and proactively handle issues. The inside structure, plan, interaction, organization, role, and environment are just a few perspectives from which these systems can be viewed. With these viewpoints, MASs may consider the structure, behavior, interaction, and environment of intricate systems like cyber-physical systems (CPS). Consequently, it is possible to model and create CPSs using intelligent software agents and MASs [31].

Figure 6 shows the architecture of an intelligent agent in artificial intelligence. Multi-agent systems are used in agriculture, as mentioned in many articles. Among these applications are [32]:

- landscape modeling, like crop location.
- Minimizing the consumption of water and determining the relationship between soil type and water.
- Providing a reduction in the energy needed in greenhouses to activate the watering pumps.
- Diminishing pesticide consumption.

Many benefits have been offered by constructing MAS in agricultural fields, particularly [33]:

- Offering the possibility to model the land.
- Water modeling with MAS enhances the management of this resource.
- Maintaining the labor has been facilitated with the MAS models.

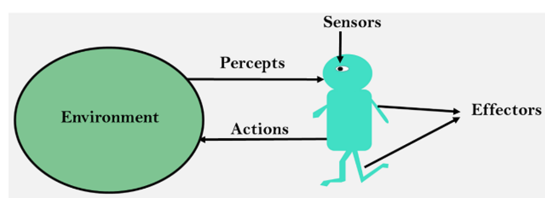

Figure 6. The architecture of an intelligent agent.

[34] presented an intelligent IoT-multiagent strategy for precision irrigation. The intelligent irrigation agent operates independently to recommend and apply appropriate amounts of water based on agronomical factors to improve irrigation system efficiency and minimize the waste of this resource. The approach was used with actual (cyber-physical) and virtual (simulated) intelligent agents.

[35] created a cyber-physical system for crop irrigation relying on the intelligent agent theory. This system enabled maintaining soil moisture near the field's capacity. Diverse irrigation techniques were applied while preventing waste and overuse of water resources.

B. Digital Twins

Michael Grieves and his partnership with John Vickers of NASA are credited with creating the Digital Twin [36]. A virtual duplicate of an actual product containing data about that object is referred to as a "Digital Twin" in the first definition, which has its roots in product life-cycle management.

The Digital Twin comprises a physical product, a virtual version of that product, bidirectional data links that feed information from the physical product to the virtual version, and information and actions from the virtual model to the real thing (see Figure 7) [37].

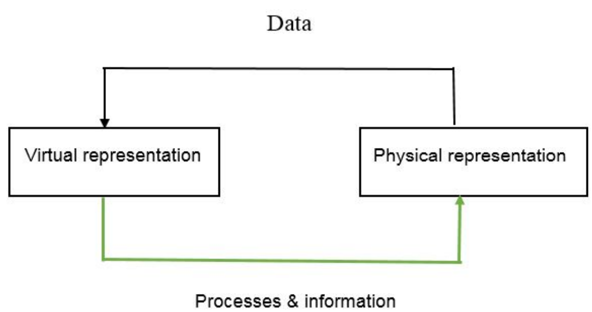

Figure 7. Digital twin process.

In agriculture, digital twins refer to the ability to represent the farm virtually to enhance the productivity of crops. However, due to the complexity of the farm process, digital twins should be incorporated separately to simulate each process individually, as depicted in Figure 8 diverse applications have been filed [38].

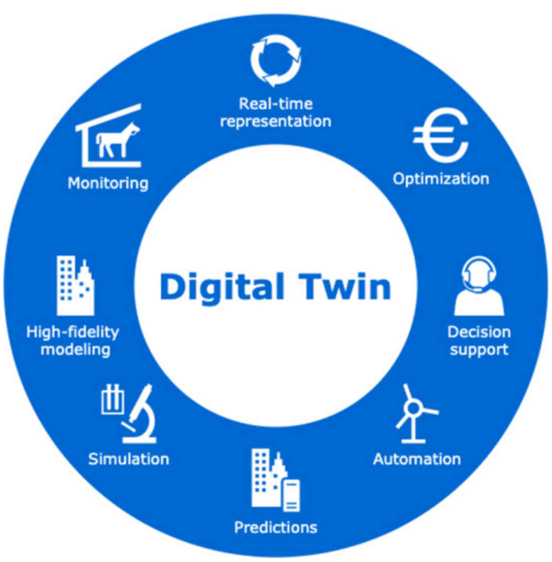

Figure 8. Digital twins applications in agriculture.

On the other hand, the integration of digital twin technology in this field is paramount not only in irrigation but in all stages, including [38]:

- Mitigation of internal and external factors that impact entity productivity.
- Simulation, planning, analysis, and improvement of crop growth.
- Maximizing yields and making farming more sustainable.
- Prediction of material vulnerabilities.
- Facilitating remote monitoring of the irrigation process.
- Enabling the tracking of water capture services.

[39] presented an overview of DT and discussed the potential applications of DT for smart agriculture in Nigeria. The benefits and drawbacks of deploying DT in agriculture have been presented. Furthermore, they have offered approaches for using DT to solve the difficulties confronting Nigeria's agriculture sector.

[40] developed a method for constructing a DT of a primary and secondary pressurized Collective Irrigation Systems (CIS) network. This system aims to assess water use efficiency and global energy. Furthermore, the effectiveness of the pumping facility, on the other hand, and energy inefficiency relating to water losses.

C. Artificial Intelligence Algorithms

Machine learning (ML) is a branch of AI that enables machines to acquire knowledge and improve their performance without explicit programming. The main goal of machine learning is to perform computer algorithms that can evolve in response to new data. ML algorithms can be divided into supervised, unsupervised, and reinforcement learning. See Figure 9 [41].

1) Supervised learning

On a predefined set of "training samples" or "training sets," the supervised learning program is "trained" [42]. Supervised learning algorithms have been widely used in irrigation, and various training sets have been mentioned in the literature. For instance, the KNN and Naive Bayes algorithms are used to anticipate soil aridity. Where the linear algorithm is used to estimate water necessities and predict the amount needed for the following water cycle and the artificial neural network algorithm is used to forecast when to turn the pump on and off [43].

2) Unsupervised learning

Unsupervised ML is when software is given data but is required to uncover patterns and relationships in that data [44]. A variety of unsupervised learning algorithms exist, among them the Apriori Algorithm. This algorithm

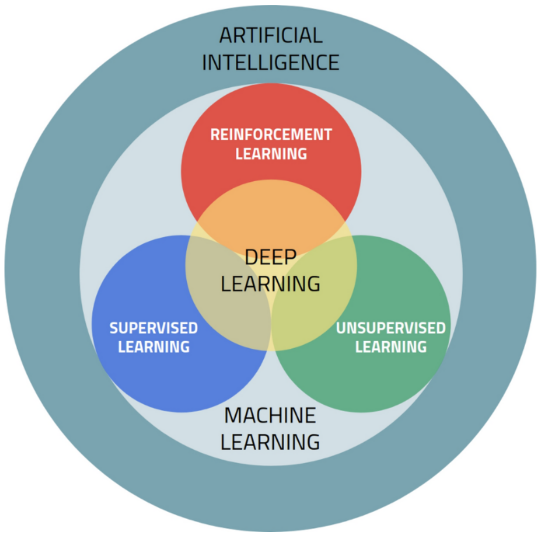

Figure 9. Machine learning classification.

is utilized to address association issues. In irrigation, the one mentioned is to estimate and forecast the suitable plant samples for a particular area [45].

3) Reinforcement learning

ML algorithms are given a reward system or a set of restrictions and generate optimal plans or courses of action. The reinforcement learning algorithms have recently attracted workers' attention in irrigation, particularly the adoption of deep reinforcement learning to schedule irrigation tasks [46]. Furthermore, managing water practices in an environment composed of agents [47].

There exist different types of machine learning algorithms, for example: The neural network like (feed-forward and recurrent), support vector machine, random forest, self-organizing map, and Bayesian network [48].

4) Deep learning

It reflects a category of machine learning techniques that focuses on representation learning and uses multilayered neural networks. It adopts a hierarchical and layered structure to reflect the provided input qualities and its current surroundings, leveraging a nested, tiered hierarchy of concept representations [49]. In agriculture, deep learning algorithms have a wide range of applications.

A novel irrigation mapping technique was developed by [50] based on convolutional neural networks that classify pixels irrigated using reflectance data from Landsat images.

In Ghana's Upper East Region, to solve the problem of dry season small-scale irrigation. [51] presented a method for mapping the explicit geographical suitability utilizing an ensemble of machine learning algorithms boosted by regression trees, random forest, and maximum entropy machine learning models.

For the irrigation scheduling task in Portugal,

[52] suggested a Deep Q-Network, with the agent environment consisting of two Long Short Term Memory models. The agent was trained to plan to water tomato crops and anticipate the amount of water that will be present in the soil profile the following day, and estimate production based on environmental conditions throughout the season.

The current revolution brought about by machine learning algorithms has captured the attention of many researchers in various fields, including agriculture. One particular area of interest is irrigation, which has witnessed a wide range of applications and increased profitability [53].

- Enabling farmers to utilize extensive data on climate change and soil conditions, directly impacting crop watering decisions.
- Facilitating informed decisions about plant management.
- Predicting the optimal timing for watering crops.
- Making management decisions to match crops with specific water requirements.
- Minimizing the adverse environmental impact of excessive watering.

Additionally, countless water management applications could be provided (see Figure 10).

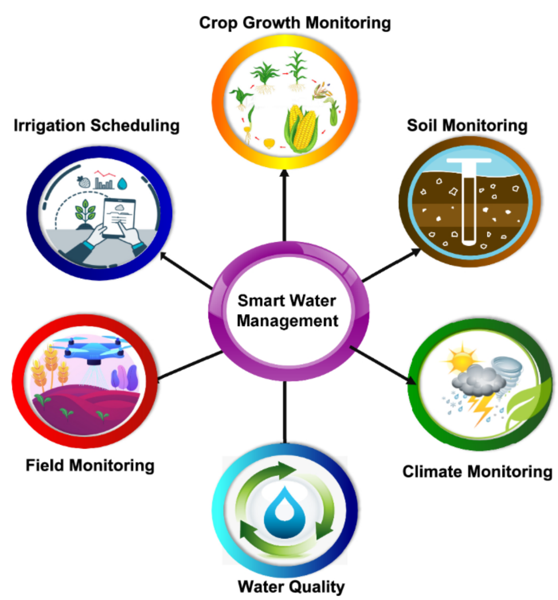

Figure 10. Machine learning applications in irrigation

D. Blockchain (BC)

BC can be defined as a chain of linked blocks of data that can be used for storing and sharing this latter in a distributed, visible, inviolable manner [54].

- Integrity and tamper resistance in the BC is offered by the linkage of blocks which is ensured using pointers.
- Whenever new data is added to the BC, a block or unit extends it, and a link is established to the open end.
- As additional data is included in the BC, it gets longer, and the chain size increases.

1) Types of BC

The BC is categorized into several types as shown in Figure 11 including [54]:

1) *Public BC*: With the possibility of free access, reading, and downloading of the data, every user can take part in a collective consensus. Then, the longest chain is extended through mining the data block.
2) *Consortium / federated BC*: A consortium of members who maintain and control the blockchain. They can read, access, generate and modify data in the block.
3) *Private BC*: This BC is not decentralized; it operates like a distributed database. This type generates novel cryptocurrencies while maintaining centralized permissions within a particular organization.

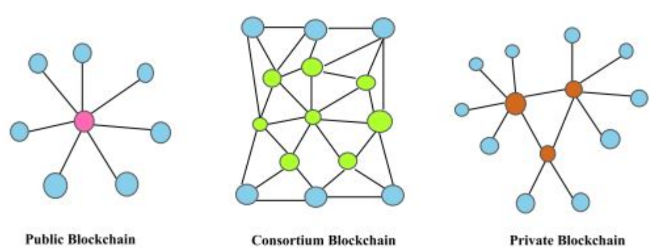

Figure 11. Types of blockchain.

Numerous works have been proposed in agriculture precisely in the irrigation phase, as Table I shows.

Blockchain technology has numerous applications in the context of irrigation, including [55]:

- Ensuring the integrity of data captured from sensors, smart devices, and actuators.
- Establishing smart contracts for managing irrigation water.
- Protecting water resource data on farms.
- Managing farmers' data

TABLE I. Different using Blockchain methods in irrigation systems

Work	Type	Objective	Method
[56]	System	Ensuring the integrity of irrigation data sensor.	• Ethereum. • Consensus proof-of-work.
[57]	Prototype	Automating the watering of the land.	Ethereum blockchain for IoT devices.
[58]	System	Secure real-time data collection for irrigation.	• Mamdani fuzzy logic model. • Distributed architecture via Blockchain.

All the mentioned technologies have transformed traditional agriculture into a new form known as Agriculture 4.0. As illustrated in Table II, each technique has distinct features and its own impact on the agricultural landscape.

TABLE II. Comparison between used technologies.

Technology	Irrigation technology	Principal features
IoT	Wireless sensor networks (WSN)	A WSN power consumption. WsN Alarms generating. WSN sensors for water, and soil calculating.
	Cloud computing	Cloud-based data storage for Irrigation.
	Intelligent agents	Simulating farm behavior by agents. Managing water distribution by agents. Agents control watering pumps.
Digital twins	Digital twins	DT for simulating pumps, and sensors. DT for simulating watering data workflow.
AI algorithms	Supervised learning	Predicting water necessities . Forecasting pump status
	Unsupervised learning	Estimating the appropriate plant based on unlabeled dataset
	Reinforcement learning	Managing water practices based on the agents.
	Deep learning	Farmland pixel images detection using convolution neural networks
Blockchain	Blockchain	Smart contract for watering Soil and weather data integrity

4. Literature Review

Various types of journal articles or conferences were analyzed in irrigation and water management. Figure 12 illustrates the number of papers analyzed in each database, and Table III summarizes these papers.

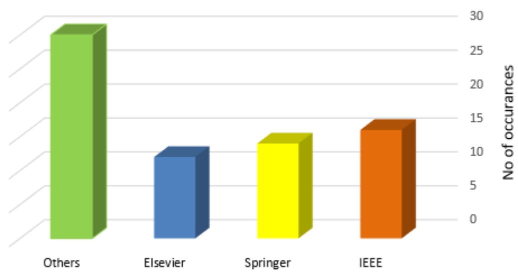

Figure 12. The number of papers that were analyzed in each database

According to the analysis results presented in Table III, the prominent problem farmers are struggling with is water wastage and adequate water due to the conventional irrigation systems. Furthermore, these papers review that using the amount of the right fertilizer, reducing environmental impact, time and water wastage problems, avoid harming soil were the crucial aim behind their works.

On the other hand, technologies like IoT, big data, machine learning, and deep learning are commonly used to solve these problems. However, it can be found that few of them have focused on the use of digital twin technology even though this latter has seen a wide range of use in several fields, including military, health care, and so on.

5. Key challenges and Open research issues

In the last years, researchers have been carrying out the enhancement of water use efficacy due to several problems that affect the agricultural field, such as resources reduction and water scarcity, water pollution caused by the highest levels of emissions of greenhouse gases (GHGs), Rainfall patterns are being disrupted by climate change, and because the agriculture field is considered as the most water user Irrigation has become a significant scientific and societal issue. The overcome these matters, farmers have used irrigation systems like flood, sprinkler, center pivot, drip, and micro-irrigation systems [67]. However, these latter needed to be increased due to water wastage. With the new age of AI and the development of IoT technologies in different sectors, researchers have employed it in irrigation systems. Incorporating these techniques aims to help farmers automate their irrigation processes and improve irrigation sustainability. But some open issues are to be addressed that offer researchers new opportunities for future work [68].

A. The Water Management Challenges

The biggest challenges of water management were

- Water pollution monitoring.
- Water reuse.
- Monitoring the irrigation system's water distribution pipeline network.

However, these challenges can be classified into two technological and systematical areas [69].

B. Technological Challenges and Directions

- Developing innovative decision support systems for managing the entire water cycle in agriculture, based on WSN and IoT, to adapt data management.
- The need for new platforms for monitoring and controlling newly developed water management systems.
- developing specialized applications for energy-efficient real-time data processing like Power real-time data analysis for control and decision making, dependable wireless communication modules with low energy consumption, and power-saving approaches for reducing sensor energy consumption.
- The design of new power-efficient solutions such as energy-efficient protocols and new powered sensors.

C. Systematical Challenges and Directions

- A predictive control model with (weather, soil, and plant) based monitoring strategies.
- Environmentally controlled agriculture research, furthermore open field agricultural irrigation systems.
- Building irrigation scheduling models for smart monitoring and control techniques on water use and production.
- The position of the leaves, discolorations on them, and the structures of Galactose trees are analyzed for detecting plant issues.

D. Digital Twin Incorporation

- The simulation of innovative irrigation processes under certain conditions.
- The need for DT-related models to analyze and forecast IoT failures and also innovative water meter behaviors while delivering consumption readings at precise times.
- Making DT-related tasks smartly would boost the solution's performance.

As a result, It is necessary to address this deficiency by developing a hybrid system that integrates the dynamic behavior of soil moisture content, weather forecast, and crop growth parameters such as fertilizers in open field tests obtained from various sensors measure weather conditions, soil properties, and plant characteristics for proper decision-making.

TABLE III. Analysis of various papers in the field of smart irrigation for the current study.

Work	Agriculture Area	Problem	Objective	Technology	Methods
[59]	Smart irrigation	The farmer's willingness to use smart irrigation apps on their farms	Reducing the environmental impact and providing the economic advantage	Smart irrigation technologies	review (survey of 678 farmers)
[60]	Irrigation	water management	Optimizing water usage by applying the right automation level	Internet of Things, Wireless Sensor Networks and Cloud Computing	Survey
[61]	Smart irrigation	The reduction of water wastage	Optimization of the use of water and fertility to increase production efficiency, reduce crop diseases	Big data, IoT, machine learning, wireless sensor networks, and cloud computing	Machine learning and data mining
[62]	Irrigation	Wasteful water use	Monitoring & Control strategies for improving irrigation efficiency	IoT technologies (sensors)	Review (2001,2020)
[63]	Water Management	Leak detection and testing of water assets under a variety of conditions	Optimized, fair, and efficient use of freshwater	Digital Twin	Intelligent software agents, to manage water consumption data
[64]	Irrigation	Inadequate irrigation	Incorporating intelligent agents on irrigation systems	Intelligent agents	Multi-agent system
[65]	Irrigation	Water scarcity	WSN in irrigation field	Wireless sensor networks (WSN)	Review (2011,2020)
[66]	Irrigation	The shortage of water	Reducing resources for crops	IoT sensors	Machine-learning algorithms

A comprehensive irrigation management strategy based on a predictive model controls the plant's nutrient and water requirements using digital twins, artificial intelligence algorithms, and IoT sensors for pest and weed detection.

6. Discussion

The literature review results show that irrigation solutions in Agriculture 4.0 are classified as Figure 13 shows.

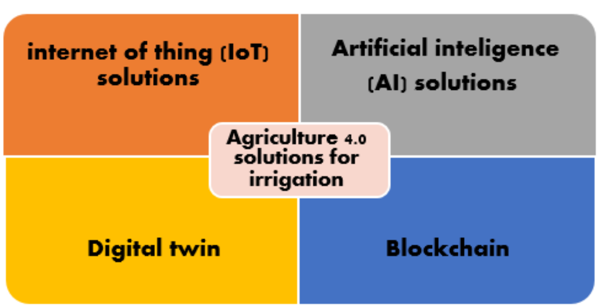

Figure 13. Agricultural solutions for irrigation.

A. IoT Solutions

Several digital technologies were included in smart irrigation systems, like wireless system networks, IoT, edge computing, and controllers specific to weather and soil sensors in the local area.

The Internet of Things has been used to automate irrigation systems by interconnecting as many devices as possible. Data is sent to a remote system via sensors.

IoT and wireless technologies offer real-time data transfer and monitoring in digital farms. In conjunction with cloud computing systems, the Internet of Things can enable interaction between software platforms and sensors, as well as machines, crops, and animals. However, some of the IoT problems that should be addressed are [70]:

- The assessment of opportunities and problems related to IoT to ensure that resources are used effectively within organizations.
- Establishing an intelligent way to provide water only where it is needed and in appropriate quantities and compatibility with IoT devices and sensing capabilities.
- Address security issues in the agricultural IoT irrigation system.

TABLE IV. Machine learning challenges with their solutions and opportunities.

ML Challenges	Solutions and Opportunities
Cloud web-based architecture accessibility for training models and installing software solutions.	• The use of similar web technology or Python Flask, Docker, etc • Deploy applications using a cloud-based platform like Amazon, or Azure Web Services.
Machine learning model generalization and underfitting along data set accessibility	cross-validation, pruning for Decision Tree and Random Forest.
A large experimental dataset is required for developing a powerful machine learning model.	Not mentioned
Expense adoption of ML and digital software applications for small-scale farmers	Cloud infrastructures like platform (PaaS), infrastructure (IaaS), and software (SaaS) as a service for irrigation management.
privacy and data security.	Not mentioned.

B. Artificial Intelligence Solutions

AI has revolutionized the world in several domains, even though it efficiently uses existing resources such as water, fertilizer, and electricity in the agricultural sector. Researchers employed different artificial intelligence techniques, such as regression and feedforward neural networks, to create an efficient smart watering system [71].

Fuzzy logic techniques assess sensor data to make irrigation system decisions. Furthermore, by including this technique in the controller system, the optimization of irrigation scheduling used in greenhouses and drainage management will be achieved [72].

1) Supervised learning

In smart farming, K nearest neighbor (KNN), support vector machines (SVM), decision trees (DT), random forests (RF), etc., were among the commonly employed supervised learning algorithms.

By enhancing the amount of water used for irrigation, scheduling, soil moisture, and weather forecasting, these techniques provide direction for irrigation decisions.

2) Unsupervised learning

Techniques such as clustering (K-Means Clustering), ANN, dimensionality reduction, hierarchical clustering, and others ensure efficient irrigation decisions throughout numerous irrigation field areas.

3) Reinforcement Learning

Generally, water management and irrigation scheduling have been improved by the use of a Deep Q-Learning (DQN) model for an irrigation decision strategy based on short-term (LSTM) weather forecasts, which are crucial for detecting water emergencies.

4) Deep Learning (DL)

Multi-agent systems MAS are commonly used to schedule irrigation. In addition to deep Q networks, supervised and unsupervised learning methods like the recurrent neural network (RNN), long short-term memory (LSTM), and convolutional neural network (CNN) was used for watering decision improvement.

Nevertheless, there are enough challenges regarding the use of these algorithms. The main challenges and solutions of machine learning are mentioned below in Table IV.

C. Blockchain Solutions

Recently, blockchain technologies have been used in agricultural IoT irrigation systems to track and identify information sharing of smart watering systems.

D. Digital Twin Solutions

- Developing digital twin applications specialized in soil and irrigation systems.
- Digital twin technology could be employed To characterize soil heterogeneity and digital soil modeling.
- Deployment of edge-computing technology for storing and analyzing information [73].

E. Analysis of Research Questions (RQ)

Results prove that major farmers intend to regulate their irrigation water due to governmental awareness about water resource scarcity and unexpected changes in rainfall patterns. Farmers usually used conventional farming equipment, such as tractors, ancient irrigation methods, and seeding machinery rented from machine cooperatives.

Farming is not very profitable due to low returns, and the high cost of technology were the two hurdles that were most frequently identified. Farmers were perplexed about where to find formal information-providing techniques and technological advancements outside of those promoted by government-sponsored annual training programs and demonstration projects. In addition to the scarcity of nearby agricultural extension agents who can provide guidance and support.

According to surveys, 90 percent of farmers think utilizing mobile and web applications for efficient irrigation management can enhance their agricultural yield and productivity.

As well as deal with water waste. this answer RQ1 as shown in Figure 14 and Table VI. The used technologies in irrigation systems, such as information communication technologies besides the IoT technologies, are listed in Tables III and VII, which address RQ2. The operation costs used in the irrigation systems, the challenges related to using intelligent technologies in irrigation systems, and the water resources and data security are shown in Table V and VII answers RQ3, RQ4, and RQ5.

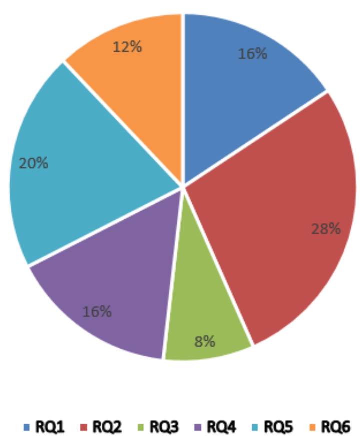

Figure 14. Distribution of the research questions by papers.

The current study described the developing digital technologies deployed in irrigation to forecast agriculture 4.0's research.

Referring to Table VII in Section 6 and what are the techniques that handle generated data in the irrigation systems and how the raw data has been dealt with (response 6), it is clear that several technologies are underutilized in the agricultural field, such as big data and analytics, WSN networks, CPSs, and digital twin.

One possible explanation for this disparity is that integrating cutting-edge technologies with more complicated tasks can be costly, at least at the beginning of the trial phase of their adoption. As a consequence, the growth of these technologies in the agricultural business is expected to accelerate in the future years.

The findings also suggest that IoT and machine learning are widely used in farms for irrigation operations due to their extensive functionality, which includes monitoring, tracking and tracing, weather forecasting, and prediction.

One of the primary research goals of the Farm 4.0 techniques is IoT and machine learning. Figure 15 depicts the critical procedures employed in irrigation systems.

Nonetheless, due to the advent of new successful methodologies and approaches, just a few studies have evaluated data security due to the usage of IoT technology when designing intelligent agricultural and multi-agent systems.

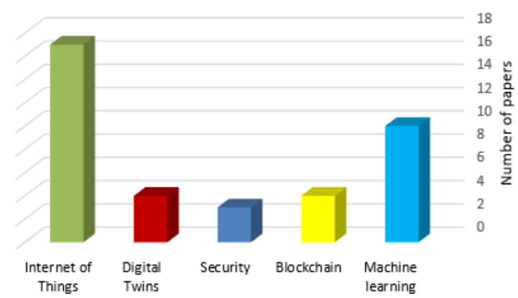

Figure 15. Technologies and methods used in irrigation systems.

Moreover, it is demonstrated that restricted research is done with digital twins, despite studies proving that their integration reduces the use of available resources. Consequently, it confirms that significant research and development are required in irrigation and some other areas to ensure successful water management, with reduced cost and energy power usage, which disadvantages preceding techniques and practices in developed and developing countries [82].

Furthermore, water scheduling and automatic irrigation with the suitable amount of water at the appropriate time. are widely mentioned in the previous studies see Table VII. However, only some have focused on the appropriate water sources for specific crops. Table VI is crucial to not losing crops and achieving the most sustainable crop production possible, and this answers RQ3. Thus the need to ensure this task is highly demanded

The agricultural environment's diversity brings several challenges and issues. As a result, strategic measures to combat them must be developed. This study makes an effort to discover what these difficulties are. Section 5 lists various concerns and obstacles based on the analysis, specifying the required actions for agricultural irrigation on a grander scale. The last stand, it is still necessary to educate farmers in rural areas about the growth scenario and the importance of improving their old irrigation systems so that they do not harm the soil or the climate to assist in effective, sustainable farming [82].

Conducting an economic cost-benefit analysis and pro-

TABLE V. The operation costs used in the irrigation and the challenges, security.

Work	Challenges and Limits operation costs	Security
[52]	The limitation in the number of actions of the deep-Q network (DQN) model	Not mentioned
[51]	the major concern of sustainable intensification, with increasing irrigated lands.	Not mentioned
[60]	Water management challenges, the management of the whole water cycle in agriculture	not mentioned
[50]	Not mentioned	Not mentioned.
[61]	The smart irrigation system with the effective combination of plant problems.	Not Mentioned
[62]	Predictive control and monitoring models with (weather, soil, and plant)	Not Mentioned
[63]	Integration of digital twins to anticipate the behaviors of smart water systems	Not mentioned
[30]	Security and a more complex decision-making system that takes into account a weighted average of sensor data	Mentioned

TABLE VI. The research questions answer.

Work	Q1	Q2	Q3	Q4	Q5	Q6
[30]	√	√	×	×	×	×
[50]	√	√	√	×	×	√
[51]	×	√	×	√	√	√
[52]	×	√	×	√	√	√
[59]	√	√	×	√	√	×
[60]	×	√	×	√	√	×
[61]	×	√	√	√	√	√
[62]	×	√	√	×	×	√
[63]	√	√	√	√	√	√
[64]	√	√	×	√	√	×
[65]	√	√	×	×	√	×
[66]	×	√	×	√	×	√
[71]	√	√	×	×	√	√
[74]	√	√	×	×	√	×
[75]	√	√	√	×	×	×
[76]	√	√	×	√	√	×
[72]	√	√	×	√	√	×
[77]	×	√	×	√	√	√
[78]	×	√	√	√	√	×
[79]	√	√	×	√	√	×
[39]	√	√	×	×	√	×
[80]	×	√	√	×	×	×
[81]	×	√	×	×	√	√

TABLE VII. Smart irrigation technologies and methods.

Work	Field	ICT/ IoT technologies	Data Set	Security	Method	Data preprocessing
[74]	Management of water resources	√	×	×	Prototype	×
[75]	Intelligent irrigation system for precision agriculture	√	WSN data, collected from the field, and satellite data	×	Machine learning	×
[76]	Irrigation	√	×	Diffie–Hellman Key Agreement	Prototype	×
[72]	Irrigation process	√	Soil, weather	×	Prototype	×
[77]	Irrigation	√	Plant's environmental condition	×	Machine learning	Data normalization removing the irrelevant noise data
[78]	Irrigation	√	Crop water uptake depth, real-time soil moisture data	×	Prototype	×
[79]	Smart Irrigation	Systems√	IoT data	RC4 and ECC Algorithms	Prototype	×
[39]	Irrigation and Fertigation	√	Soil, plant, and weather data	×	Digital twins	×
[80]	Irrigation processes	√	Potato crops data, Weather data	×	Multi-agent system	×
[81]	Autonomous crop irrigation	√	Moisture in the soil, pesticides, and fertilizers	×	Multi-agent system, ML	The information fusion agent
[83]	Soil tracking and determining irrigation	√	Sensor data like PH, temperature and relative humidity, sunlight hours, and precipitation amount, etc.	×	WSNs	Data regularization(mathematical adjusting)
[84]	Controlling irrigation	√	soil moisture	√	Prototype	×
[85]	Farm managing and irrigation	√	NSL-KDD dataset	√	IoT devices and ML	Missing values and dimension reduction as a preprocessing phase, Data balancing, Feature selection.
[86]	Controlling irrigation	√	NSL-KDD dataset	√	Machine learning	Converting symbolic features to numeric features, Feature extraction
[87]	Smart irrigation	√	soil, weather and crop data	×	Digital twins	Data aggregation
[88]	Smart irrigation	√	soil, weather,water quality and crop data	×	Overview	×

viding details on particular technologies are crucial in addressing the primary obstacle to adoption, which is the expense (cost), which includes highlighting the long-term financial advantages of adoption and working to enhance interpretations and interactions to support farmer judgment and uptake.

Offering organized training programs on IoT and big data applications in agriculture may enable farmers to implement smart farming practices more successfully [89].

It is evident that integrating smart technologies is expected to enhance water resource management, leading to increased efficiency. Moreover, farmers' awareness is necessary when integrating these technologies to augment their profitability, not only in irrigation activities but also in other agricultural practices that are not covered in our research. Addressing these limitations provides a more informed and balanced perspective on the future of farming.

7. Conclusions and Future Work

In this study, we survey the numerous technologies, models of artificial intelligence algorithms, methodologies, and sensors related to irrigation using IoT. According to the research, there has been an increase in the past few years in the amount of literature on smart technologies that control or model irrigation systems.

As a result, there may continue to contribute in various ways to this growing research area. Because IoT technology allows physical objects to be represented on the Internet, data transmission between devices is simplified. IoT has become a fundamental technology commonly employed in smart irrigation system alternatives, allowing for simplified data gathering, monitoring, and remote control of these systems. This IoT is utilized for farm management and future prediction via machine learning algorithms for agricultural surveys and to improve current watering services. Moreover, We have explored irrigated agriculture in IoT, water concerns and issues, and digital twins technology.

To achieve water sustainability and enhance the effectiveness of their use. According to irrigation system developers, smart irrigation outperforms traditional irrigation concerning efficiency and timeliness; this demonstrates the importance of research into intelligent irrigation systems in improving agricultural processes.

This paper notably emphasizes the applied technologies and methods to irrigation systems, considering distinct techniques like blockchain, machine learning, intelligent agents, etc. For future work, there will be a consideration of different agricultural phases, such as tackling diseases, fertilization, harvesting, pesticides, and herbicides, enabling the researchers to adapt to the new technological revolution in farming systems.

References

[1] "Climate change — food and agriculture organization of the united nations," https://www.fao.org/climate-change/en/, accessed: March 29, 2023.

[2] "Chapter 1. introduction," https://www.fao.org/3/s8684e/s8684e02.htm#chapter, note = Accessed: March 29, 2023 .

[3] M. Vatanpour, S. Toursavadkouhi, and S. Sajjad, "Comparison of three irrigation methods: Sweeps, ultrasonic, and traditional irrigation, in smear layer and debris removal abilities in the root canal, beyond the fractured instrument." *Photodiagnosis and photodynamic therapy*, vol. 37, p. 102707, 2022.

[4] X. Sun, J. Tong, C. Liu, and Y. Ma, "Using hydrus-2d model to simulate the water flow and nitrogen transport in a paddy field with traditional flooded irrigation," *Environmental Science and Pollution Research*, vol. 29, no. 22, pp. 32 894–32 912, 2022.

[5] B. Matyakubov, D. Nurov, U. Teshaev, and K. Kobulov, "Drip irrigation advantages for the cotton field in conditions of salty earth in bukhara province region," in *IOP Conference Series: Earth and Environmental Science*, vol. 1138, no. 1. IOP Publishing, 2023, p. 012016.

[6] S. Debnath, S. Adamala, and D. Palakuru, "An overview of indian traditional irrigation systems for sustainable agricultural practices," vol. 9, pp. 237–244, 01 2020.

[7] J. Weerahewa, J. Timsina, M. Wickramasinghe, S. Mimasha, D. Dayananda, and D. G. Pushpakumara, "Ancient irrigation systems in asia and africa: Typologies, degradation and ecosystem services," *Agricultural Systems*, vol. 205, 02 2023.

[8] A. Mungsunti, K. Parton, A. Yusuf, and T. Kewprasopsak, "Survey data of a traditional communal water irrigation system in northern thailand," *Data in Brief*, vol. 44, p. 108515, 08 2022.

[9] M. Rashad, A. Zedan, A. Khedr, and C. Mark, "Journal of soil sciences and agricultural engineering creating software to design a low-head bubbler irrigation system as an alternative to traditional furrow irrigation," *Journal of Soil Sciences and Agricultural Engineering*, vol. 12, pp. 797–803, 11 2021.

[10] C. Cusack, A. Fernald, D. VanLeeuwen, S. Guldan, T. Baker, and R. Heyduck, "Supporting riparian habitat with traditional irrigation systems of the northern rio grande region," *The Southwestern Naturalist*, vol. 66, 11 2022.

[11] M. McCaig, D. Rezania, and R. Dara, "Framing the response to iot in agriculture: A discourse analysis," *Agricultural Systems*, vol. 204, p. 103557, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0308521X22001937

[12] M. Nagarajapandian, R. Savitha, and D. Shanthi, "An advanced irrigation system for smart agriculture using the internet of things," in *Proceedings of the 3rd International Conference on Communication, Devices and Computing: ICCDC 2021*. Springer, 2022, pp. 619–629.

[13] A. Chauhan, R. R. Sah, and R. Khatri, "Iot-based smart irrigation system—a hardware review," in *IOT with Smart Systems: Proceedings of ICTIS 2021, Volume 2*. Springer, 2022, pp. 647–659.

[14] G. Khan, A. Shukla, and S. Kundu, "Iot based smart irrigation system," in *AIP Conference Proceedings*, vol. 2427, no. 1. AIP Publishing LLC, 2023, p. 020053.

[15] Y. Gamal, A. Soltan, L. A. Said, A. H. Madian, and A. G. Radwan, "Smart irrigation systems: Overview," *IEEE Access*, 2023.

[16] D. Vallejo-Gómez, M. Osorio, and C. A. Hincapié, "Smart irrigation systems in agriculture: A systematic review," *Agronomy*, vol. 13, no. 2, p. 342, 2023.

[17] L. Atzori, A. Iera, G. Morabito, and M. Nitti, "The social internet of things (siot)–when social networks meet the internet of things: Concept, architecture and network characterization," *Computer networks*, vol. 56, no. 16, pp. 3594–3608, 2012.

[18] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer networks*, vol. 54, no. 15, pp. 2787–2805, 2010.

[19] S. K. Mousavi, A. Ghaffari, S. Besharat, and H. Afshari, "Improving the security of internet of things using cryptographic algorithms: a case of smart irrigation systems," *Journal of Ambient Intelligence and Humanized Computing*, vol. 12, pp. 2033–2051, 2021.

[20] M. Mustafa, A. Abbas, Q. Bsoul, and A. Shabbir, "Smart irrigation system based on the internet of things and the cloud," *Int. J. Mod. Trends Sci. Technol*, vol. 7, no. 09, pp. 19–24, 2021.

[21] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer networks*, vol. 52, no. 12, pp. 2292–2330, 2008.

[22] A. Touhami, S. Touhami, N. Touhami, K. Benahmed, and F. Bounaama, "Design of smart irrigation system in the greenhouse using wsn and renewable energies," in *Advanced Computational Techniques for Renewable Energy Systems*. Springer, 2023, pp. 126–131.

[23] P. Bedi, S. Goyal, J. Kumar, and S. Kumar, "Chapter 8 - analysis of energy-efficient cluster-based routing protocols for heterogeneous wsns," in *Comprehensive Guide to Heterogeneous Networks*, K. Ahuja, A. Nayyar, and K. Sharma, Eds. Academic Press, 2023, pp. 217–247. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780323905275000034

[24] S. G. Rozario and V. Vasanthi, "Groundwater monitoring and irrigation scheduling using wsn," in *Intelligent and Cloud Computing: Proceedings of ICICC 2021*. Springer, 2022, pp. 165–175.

[25] A. B. Amin, G. O. Dubois, S. Thurel, J. Danyluk, M. Boukadoum, and A. B. Diallo, "Wireless sensor network and irrigation system to monitor wheat growth under drought stress," in *2021 IEEE International Symposium on Circuits and Systems (ISCAS)*. IEEE, 2021, pp. 1–4.

[26] M. S. Mahmoud and Y. Xia, "Chapter 3 - cloud computing," in *Networked Control Systems*, M. S. Mahmoud and Y. Xia, Eds. Butterworth-Heinemann, 2019, pp. 91–125. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128161197000113

[27] A. Merizig, O. Kazar, and M. Lopez-Sanchez, "A dynamic and adaptable service composition architecture in the cloud based on a multi-agent system," *International Journal of Information Technology and Web Engineering (IJITWE)*, vol. 13, no. 1, pp. 50–68, 2018.

[28] A. Merizig, O. Kazar, and M. L. Sanchez, "A multi-agent system approach for service deployment in the cloud," *International Journal of Communication Networks and Distributed Systems*, vol. 23, no. 1, pp. 69–92, 2019.

[29] A. Al-Qammaz, K. A. Darabkh, L. Abualigah, A. M. Khasawneh, Z. Zinonos *et al.*, "An ai based irrigation and weather forecasting system utilizing lorawan and cloud computing technologies," in *2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus)*. IEEE, 2021, pp. 443–448.

[30] M. Younes and A. Salman, "A cloud-based application for smart irrigation management system," in *2021 8th International Conference on Electrical and Electronics Engineering (ICEEE)*. IEEE, 2021, pp. 85–92.

[31] R. Singh, "Intelligent agents," in *Encyclopedia of Information Systems*, H. Bidgoli, Ed. New York: Elsevier, 2003, pp. 639–647. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B0122272404000940

[32] M. E. P. Pons, J. P. Domínguez, J. M. C. Rodríguez, J. Meira, and M. G. C. Marreiros, "Review on the applications of multi-agent systems in agriculture," in *Proceedings of the IV Workshop on Disruptive Information and Communication Technologies for Innovation and Digital Transformation: 18th June 2021 Online*. Ediciones Universidad de Salamanca, 2022, pp. 49–57.

[33] W. Kaye-Blake, F. Li, A. Martin, A. McDermott, S. Rains, S. Sinclair, and A. Kira, "Multi-agent simulation models in agriculture: A review of their construction and uses," *Publisher: Lincoln University.ISBN: 978-1-877519-08-6. URL http://hdl.handle.net/10182/1928*, 03 2010.

[34] A.-F. Jiménez, P.-F. Cárdenas, and F. Jiménez, "Intelligent iot-multiagent precision irrigation approach for improving water use efficiency in irrigation systems at farm and district scales," *Computers and Electronics in Agriculture*, vol. 192, p. 106635, 2022.

[35] A.-F. Jimenez, P.-F. Cardenas, F. Jimenez, A. Ruiz-Canales, and A. López, "A cyber-physical intelligent agent for irrigation scheduling in horticultural crops," *Computers and Electronics in Agriculture*, vol. 178, p. 105777, 2020.

[36] S. Liu, J. Bao, and P. Zheng, "A review of digital twin-driven machining: From digitization to intellectualization," *Journal of Manufacturing Systems*, vol. 67, pp. 361–378, 2023.

[37] D. Jones, C. Snider, A. Nassehi, J. Yon, and B. Hicks, "Characterising the digital twin: A systematic literature review," *CIRP Journal of Manufacturing Science and Technology*, vol. 29, pp. 36–52, 2020.

[38] W. Purcell and T. Neubauer, "Digital twins in agriculture: A state-of-the-art review," *Smart Agricultural Technology*, vol. 3, p. 100094, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2772375522000594

[39] O. Elijah, S. K. A. Rahim, A. A. Emmanuel, Y. O. Salihu, Z. G. Usman, and A. M. Jimoh, "Enabling smart agriculture in nigeria: Application of digital-twin technology," in *2021 1st International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS)*. IEEE, 2021, pp. 1–6.

[40] M. Moreira, S. Mourato, C. Rodrigues, S. Silva, R. Guimarães, and C. Chibeles, "Building a digital twin for the management of pressurised collective irrigation systems," in *Proceedings of the 1st International Conference on Water Energy Food and Sustainability (ICoWEFS 2021)*. Springer, 2021, pp. 785–795.

[41] J. M. Helm, A. M. Swiergosz, H. S. Haeberle, J. M. Karnuta, J. L. Schaffer, V. E. Krebs, A. I. Spitzer, and P. N. Ramkumar, "Machine learning and artificial intelligence: definitions, applications, and future directions," *Current reviews in musculoskeletal medicine*, vol. 13, pp. 69–76, 2020.

[42] S. Raschka, J. Patterson, and C. Nolet, "Machine learning in python: Main developments and technology trends in data science, machine learning, and artificial intelligence," *Information*, vol. 11, no. 4, p. 193, 2020.

[43] A. Stephen, A. Punitha, and A. Chandrasekar, "Irrigation system based on iot and machine learning approach," in *International Virtual Conference on Industry 4.0*, R. J. Kannan, S. Geetha, S. Sashikumar, and C. Diver, Eds. Singapore: Springer Nature Singapore, 2023, pp. 57–65.

[44] K. El Bouchefry and R. S. de Souza, "Chapter 12 - learning in big data: Introduction to machine learning," in *Knowledge Discovery in Big Data from Astronomy and Earth Observation*, P. Škoda and F. Adam, Eds. Elsevier, 2020, pp. 225–249. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128191545000230

[45] R. Ramprashath, T. Vedhanayagan, S. Nesamani, S. Mathiyarasan, and L. Mukesh, "The advancement of an imperishable method for agriculture production using seawater based on machine learning algorithm," *Journal of Survey in Fisheries Sciences*, vol. 10, no. 4S, pp. 1633–1654, 2023.

[46] Y. Saikai, A. Peake, and K. Chenu, "Deep reinforcement learning for irrigation scheduling using high-dimensional sensor feedback," *arXiv preprint arXiv:2301.00899*, 2023.

[47] M. Madondo, M. Azmat, K. Dipietro, R. Horesh, M. Jacobs, A. Bawa, R. Srinivasan, and F. O'Donncha, "A swat-based reinforcement learning framework for crop management," *arXiv preprint arXiv:2302.04988*, 2023.

[48] P. Schneider and F. Xhafa, "Chapter 8 - machine learning: Ml for ehealth systems," in *Anomaly Detection and Complex Event Processing over IoT Data Streams*, P. Schneider and F. Xhafa, Eds. Academic Press, 2022, pp. 149–191. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128238189000195

[49] C. Janiesch, P. Zschech, and K. Heinrich, "Machine learning and deep learning," *Electronic Markets*, vol. 31, no. 3, pp. 685–695, 2021.

[50] T. Colligan, D. Ketchum, D. Brinkerhoff, and M. Maneta, "A deep learning approach to mapping irrigation using landsat: Irrmapper u-net," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1–11, 2022.

[51] K. Akpoti, T. P. Higginbottom, T. Foster, R. Adhikari, and S. J. Zwart, "Mapping land suitability for informal, small-scale irrigation development using spatial modelling and machine learning in the upper east region, ghana," *Science of the Total Environment*, vol. 803, p. 149959, 2022.

[52] K. Alibabaei, P. D. Gaspar, E. Assunção, S. Alirezazadeh, and T. M. Lima, "Irrigation optimization with a deep reinforcement learning model: Case study on a site in portugal," *Agricultural Water Management*, vol. 263, p. 107480, 2022.

[53] V. Meshram, K. Patil, V. Meshram, D. Hanchate, and S. Ramkteke, "Machine learning in agriculture domain: A state-of-art survey," *Artificial Intelligence in the Life Sciences*, vol. 1, p. 100010, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2667318521000106

[54] U. Bodkhe, S. Tanwar, P. Bhattacharya, and N. Kumar, "Blockchain for precision irrigation: Opportunities and challenges," *Transactions on Emerging Telecommunications Technologies*, vol. 33, no. 10, p. e4059, 2022.

[55] F. M. Enescu, N. Bizon, A. Onu, M. S. Răboacă, P. Thounthong, A. G. Mazare, and G. Șerban, "Implementing blockchain technology in irrigation systems that integrate photovoltaic energy generation systems," *Sustainability*, vol. 12, no. 4, p. 1540, Feb 2020. [Online]. Available: http://dx.doi.org/10.3390/su12041540

[56] A. Sumarudin, W. P. Putra, A. Puspaningrum, A. Suheryadi, I. S. Anam, M. Yani, and I. Hanif, "Implementation of iot sensored data integrity for irrigation in precision agriculture using blockchain ethereum," in *2022 5th International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, 2022, pp. 29–33.

[57] U. Divakarla and K. Chandrasekaran, "Automation with blockchain: Creating a marketplace for iot based irrigation system," in *Advanced Network Technologies and Intelligent Computing*, I. Woungang, S. K. Dhurandher, K. K. Pattanaik, A. Verma, and P. Verma, Eds. Cham: Springer Nature Switzerland, 2023, pp. 60–72.

[58] I. Jdey, "Trusted smart irrigation system based on fuzzy iot and blockchain," in *Service-Oriented Computing – ICSOC 2022 Workshops*, J. Troya, R. Mirandola, E. Navarro, A. Delgado, S. Segura, G. Ortiz, C. Pautasso, C. Zirpins, P. Fernández, and A. Ruiz-Cortés, Eds. Cham: Springer Nature Switzerland, 2023, pp. 154–165.

[59] A. Hadidi, D. Saba, and Y. Sahli, "Smart irrigation system for smart agricultural using iot: concepts, architecture, and applications," *The digital agricultural revolution: innovations and challenges in agriculture through technology disruptions*, pp. 171–198, 2022.

[60] A. Saad, A. Gamatié *et al.*, "Water management in agriculture: a survey on current challenges and technological solutions," *IEEE Access*, vol. 8, pp. 38 082–38 097, 2020.

[61] H. Nandanwar, A. Chauhan, D. Pahl, and H. Meena, "A survey of application of ml and data mining techniques for smart irrigation system," in *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)*. IEEE, 2020, pp. 205–212.

[62] E. Bwambale, F. K. Abagale, and G. K. Anornu, "Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review," *Agricultural Water Management*, vol. 260, p. 107324, 2022.

[63] S. Zekri, N. Jabeur, and H. Gharrad, "Smart water management using intelligent digital twins," *COMPUTING AND INFORMATICS*, vol. 41, no. 1, p. 135–153, Apr. 2022. [Online]. Available: https://www.cai.sk/ojs/index.php/cai/article/view/2022_1_135

[64] A.-F. Jimenez, P.-F. Cardenas, A. Canales, F. Jimenez, and A. Portacio, "A survey on intelligent agents and multi-agents for irrigation scheduling," *Computers and Electronics in Agriculture*, vol. 176, p. 105474, 2020.

[65] L. Hamami and B. Nassereddine, "Application of wireless sensor networks in the field of irrigation: A review," *Computers and Electronics in Agriculture*, vol. 179, p. 105782, 2020.

[66] B. Gomathy, R. Balasubramanian, S. Barkavi, and G. Gowarthini, "Machine learning based smart irrigation system," *Annals of the Romanian Society for Cell Biology*, pp. 596–601, 2021.

[67] D. Boutheina, M. Amel, K. Sami, B. S. Fatma, M. Bassem *et al.*, "Agricultural water management practices in mena region facing climatic challenges and water scarcity," *Water Conservation & Management (WCM)*, vol. 6, no. 1, pp. 39–44, 2022.

[68] A. Gupta, R. k. Singh, M. Kumar, C. P. Sawant, and B. B. Gaikwad, "On-farm irrigation water management in india: Challenges and research gaps," *Irrigation and Drainage*, vol. 71, no. 1, pp. 3–22, 2022.

[69] C. Kang, G. Diverres, M. Karkee, Q. Zhang, and M. Keller, "Decision-support system for precision regulated deficit irrigation management for wine grapes," *Computers and Electronics in Agriculture*, vol. 208, p. 107777, 2023.

[70] D. A. Aziz, R. Asgarnezhad, and S. N. Mahmood, "The recent advances in iot based smart plant irrigation systems: a brief review," in *2021 5th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*. IEEE, 2021, pp. 97–104.

[71] E. A. Abioye, O. Hensel, T. J. Esau, O. Elijah, M. S. Z. Abidin, A. S. Ayobami, O. Yerima, and A. Nasirahmadi, "Precision irrigation management using machine learning and digital farming solutions," *AgriEngineering*, vol. 4, no. 1, pp. 70–103, 2022.

[72] G. L. P. L. J. JM, "Lloret j lorenz p iot-based smart irrigation systems: An overview on the recent trends on sensors and iot systems for irrigation in precision agriculture," *Sensors*, vol. 20, no. 4, p. 1042, 2020.

[73] A. Nasirahmadi and O. Hensel, "Toward the next generation of digitalization in agriculture based on digital twin paradigm," *Sensors*, vol. 22, no. 2, p. 498, 2022.

[74] D. Masseroni, G. Arbat, and I. P. de Lima, "Managing and planning water resources for irrigation: Smart-irrigation systems for providing sustainable agriculture and maintaining ecosystem services," p. 263, 2020.

[75] A. D. Boursianis, M. S. Papadopoulou, A. Gotsis, S. Wan, P. Sarigiannidis, S. Nikolaidis, and S. K. Goudos, "Smart irrigation system for precision agriculture—the arethou5a iot platform," *IEEE Sensors Journal*, vol. 21, no. 16, pp. 17 539–17 547, 2020.

[76] S. Nashwan, "Secure authentication scheme using diffie–hellman key agreement for smart iot irrigation systems," *Electronics*, vol. 11, no. 2, p. 188, 2022.

[77] K. Bakthavatchalam, B. Karthik, V. Thiruvengadam, S. Muthal, D. Jose, K. Kotecha, and V. Varadarajan, "Iot framework for measurement and precision agriculture: predicting the crop using machine learning algorithms," *Technologies*, vol. 10, no. 1, p. 13, 2022.

[78] R. Liao, S. Zhang, X. Zhang, M. Wang, H. Wu, and L. Zhangzhong, "Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept," *Agricultural Water Management*, vol. 245, p. 106632, 2021.

[79] S. K. Mousavi, A. Ghaffari, S. Besharat, and H. Afshari, "Security of internet of things using rc4 and ecc algorithms (case study: smart irrigation systems)," *Wireless Personal Communications*, vol. 116, pp. 1713–1742, 2021.

[80] A. González-Briones, J. A. Castellanos-Garzón, Y. Mezquita-Martín, J. Prieto, and J. M. Corchado, "A multi-agent system framework for autonomous crop irrigation," in *2019 2nd International Conference on Computer Applications & Information Security (ICCAIS)*. IEEE, 2019, pp. 1–6.

[81] A. González-Briones, Y. Mezquita, J. A. Castellanos-Garzón, J. Prieto, and J. M. Corchado, "Intelligent multi-agent system for water reduction in automotive irrigation processes," *Procedia Computer Science*, vol. 151, pp. 971–976, 2019.

[82] R. Abbasi, P. Martinez, and R. Ahmad, "The digitization of agricultural industry–a systematic literature review on agriculture 4.0," *Smart Agricultural Technology*, p. 100042, 2022.

[83] L. García, L. Parra, J. M. Jimenez, M. Parra, J. Lloret, P. V. Mauri, and P. Lorenz, "Deployment strategies of soil monitoring wsn for precision agriculture irrigation scheduling in rural areas," *Sensors*, vol. 21, no. 5, p. 1693, 2021.

[84] K. Kethineni and G. Pradeepini, "Design of security surveillance and automatic water system for agriculture," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 11, no. 2, pp. 212–215, 2023.

[85] A. El-Ghamry, A. Darwish, and A. E. Hassanien, "An optimized cnn-based intrusion detection system for reducing risks in smart farming," *Internet of Things*, vol. 22, p. 100709, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S254266052300032X

[86] A. Raghuvanshi, U. K. Singh, G. S. Sajja, H. Pallathadka, E. Asenso, M. Kamal, A. Singh, and K. Phasinam, "Intrusion detection using machine learning for risk mitigation in iot-enabled smart irrigation in smart farming," *Journal of Food Quality*, vol. 2022, pp. 1–8, 2022.

[87] R. G. Alves, R. F. Maia, and F. Lima, "Development of a digital twin for smart farming: Irrigation management system for water saving," *Journal of Cleaner Production*, vol. 388, p. 135920, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0959652623000781

[88] L. García, L. Parra, J. M. Jimenez, J. Lloret, and P. Lorenz, "Iot-based smart irrigation systems: An overview on the recent trends on sensors and iot systems for irrigation in precision agriculture," *Sensors*, vol. 20, no. 4, p. 1042, 2020.

[89] N. B. K. Zaman, W. N. A. A. Raof, A. R. Saili, N. N. Aziz, F. A. Fatah, and S. K. Vaiappuri, "Adoption of smart farming technology among rice farmers," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 29, no. 2, pp. 268–275, 2023.

Roufaida Khebbache received the Bachelor degree in computer science from the University of Biskra, Algeria and the master's degree in computer science from the University of Biskra, Algeria, in 2017 and 2019, respectively. She is currently working towards a PhD degree at the University of Biskra. She is affiliated with the LINFI laboratory. Her research interests include artificial intelligence and machine learning methods in smart farming. She can be contacted at roufaida.khebbache@univ-biskra.dz.

Abdelhak Merizig received his B.Sc. and M.Sc. degrees in Computer science in 2011 and 2013, and his Ph.D. degree in 2018 from Mohamed Khider University, Biskra, Algeria, He is working in the artificial intelligence field. He is now an Assistant Professor at the computer science department of Biskra University. Also, he has been a member of the LINFI Laboratory at the same University since 2013. He is a member of several TPC at conferences and acts as a reviewer in different journals. His research interests include Agriculture 4.0, multi-agent systems, human-machine Interaction, Cloud computing, and the Internet of Things. He can be contacted at a.merizig@univ-biskra.dz.

Khaled Rezeg was born in Biskra (Algeria) in 1968. He received the engineer degree in computer science from Annaba University, Annaba, Algeria, in 1992, his magister degree in computer science in artificial intelligence and imagery (2003), his Doctoral degree (2011), and his university habilitation degree (2015) from the University of Biskra (Algeria). He is a full professor in the computer science department of the University of Biskra since 2021. He is a researcher with the LINFI laboratory since 2013. He has been the head of a team in the same laboratory since 2013. Pr. Rezeg is a member of many TPCs at conferences and acts as a reviewer in several journals. In fact, Pr Rezeg is interested in: Geographic Information Systems, Human-Machine interface engineering, ontologies, and automatic natural language processing. He can be contacted at k.rezeg@univ-biskra.dz.

Jaime Lloret received his B.Sc.+M.Sc. in Physics in 1997, his B.Sc.+M.Sc. in electronic Engineering in 2003 and his Ph.D. in telecommunication engineering (Dr. Ing.) in 2006. He is a Cisco Certified Network Professional Instructor and he has 7 Cisco Networking Academy Certifications. He also has the Hewlett-Packard IT Architect Certification. He worked as a network designer and administrator in several enterprises. He is a Full Professor at the Polytechnic University of Valencia. He is the director of the University Diploma “Redes y Comunicaciones de Ordenadores” and he has been the director of the University Master ”Digital Post Production” for the term 2012-2016. He was Vice-chair for the Europe/Africa Region of Cognitive Networks Technical Committee (IEEE Communications Society) for the term 2010-2012 and Vice-chair of the Internet Technical Committee (IEEE Communications Society and Internet society) for the term 2011-2013. Moreover, he is included in the world’s top 2% scientists according to the Stanford University List since 2020. He has been involved in more than 500 Program committees of international conferences, and more than 160 organization and steering committees. He has been general chair (or co-chair) of 78 International workshops and conferences. He is IEEE Senior, ACM Senior, IARIA Fellow and EAI Fellow. He can be contacted at jlloret@dcom.upv.es.