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Smart Plant Watering System

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Abstract: *Through a methodical evaluation of the literature found in numerous digital repositories, this research offers a thorough analysis of smart agricultural solutions. The components and technology used in these systems are categorised methodologically into the following groups: sensors, actuators, gateways, power supply, networking, data storage, data processing, and information delivery. Using this data, we determine which gadgets and technologies are most frequently used in smart agricultural solutions and talk about how they are used in the suggested categories. By combining the data collected, we provide an understanding of the state of smart farming today along with suggestions for the choice of equipment and technology for each category. This study advances our knowledge of smart agricultural technology and helps stakeholders make well-informed choices about putting such solutions into practice.*

Keywords: Internet of Things, LoRaWAN, network, sensors, WiFi, wireless communication, and smart farming

I. INTRODUCTION

The Internet of Things (IoT) is a global network of intelligent devices that can communicate information, organise themselves, and react to changes in their surroundings [1]. These components, sometimes referred to as "smart things," include everything from sensors and gadgets to domestic appliances and machinery. Three major stages have been identified in the development of the Internet of Things. The first phase, which lasted from 2002 to 2009, was marked by a limited number of publications and an initial slow progress. IoT attention started to take shape around this time, as seen by the publication of important reports like the International Telecommunication Union's 2005 report. The following stage is called the development phase, and it lasts from 2009 to 2015. At this period, a number of nations, notably the European fields for applications. Lastly, the period of rapid expansion, which lasted from 2015 to 2019, was marked by a significant rise in research in a number of domains, including industry, smart cities, medicine, and agriculture, among others, as well as the publication of IoT-related publications. Publications increased quickly during this time, indicating increased interest and progress in the IoT space [2].

The importance of IoT resides in its revolutionary potential to change how people interact with the physical environment. In the end, IoT improves operational efficiency, lowers costs, and creates new business prospects by facilitating faster and more accurate decision-making through real-time data collecting and analysis. As previously said, IoT finds use in a variety of fields, such as:

- **Smart mobility:** IoT is used for traffic management, vehicle tracking, intelligent transportation systems, route optimization, intelligent parking lots, among other things.
- **Smart grid:** IoT is utilised to monitor electricity consumption in real time and manage energy efficiently. optimisation of energy distribution, incorporation of renewable energy sources, etc..
- **Smart Home:** This category includes energy management, security and surveillance, comfort and energy efficiency, home automation, and control of linked devices.
- **Monitoring of the Environment and Public Safety:** IoT is utilised for early warning systems, managing natural disasters, monitoring the quality of the air and water, and detecting pollutants.
- **Medicine and healthcare:** IoT is used for connected medical devices, remote patient monitoring, drug management, real-time health monitoring, etc.
- **Industry 4.0:** IoT is utilised for supply chain management, quality control, predictive maintenance of machinery, process monitoring and optimisation, and many more applications.

- **Breeding:** IoT technologies are harnessed for compre- hensive livestock management and monitoring of animal health. [3].

Smart farming is one of these many sectors where IoT is being used extensively. IoT is crucial to smart farming because it can collect data in real time from linked sensors and actuators. This makes it possible to optimise resources, automate tasks, and make well-informed decisions—all of which contribute to more productive and sustainable farming methods. For example, a study cited in [4] demonstrates how IoT integration in smart agriculture can offer significant advantages that raise farming operations' sustainability, productivity, and efficiency. IoT also makes it possible for agriculture to adopt a data-driven, intelligent management strategy that aids in farmers' decision-making. Their cultivation and harvesting methods can be optimised as a result, greatly increasing their profitability.

Despite the obvious advantages that contemporary agricultural technologies could offer the farming industry, a major obstacle to their widespread adoption is farmers' ignorance. Agriculture is an essential part of many economies, as numerous studies have shown, yet the conditions that farmers face frequently include a lack of financial resources, knowledge, and technology [5]. In contrast to contemporary techniques that use mechanised equipment and hybrid seeds, traditional agricultural practices—such as manual labour-intensive chores like tilling, sowing, and harvesting—remain prevalent in many locations [5]. According to the literature, there are a number of obstacles to putting smart agricultural solutions into practice, including unclear standards, coverage and connectivity problems, high costs, reluctance to adopt new technology, and a lack of skilled labour [6]. Furthermore, the lack of models that provide guidance on the components required for IoT-based monitoring systems hinders the adoption of smart farming [7]. The fact that most farmers in rural areas lack formal education, which leads to a lack of awareness and comprehension of IoT technology, is another major barrier.

and possible uses for them [8]. Efforts must be focused on educating farmers about IoT technology and showing them how these advancements can improve production, efficiency, and income on their farms in order to overcome these obstacles and realise the full potential of contemporary agricultural techniques [8].

Common reviews of the literature indicate that resolving issues and enhancing effectiveness in particular situations, such greenhouse farming, are of utmost importance. For instance, [9] highlights that a key feature of their particular situation is the automatic reconfiguration of control systems. Their objective is to increase agricultural operations' efficiency in order to minimise resource waste and provide ideal growing conditions for crops.

This comprehensive analysis covers a range of smart farming architectures and systems intended to help farmers find the best parts for customised solutions to meet certain requirements. Our research looks at whole solutions, acknowledging that each part and the technology that goes with it might have different effects on crop development. Additionally, our study assesses the latest infrastructure elements used in smart agriculture and outlines their benefits. We have determined relevant criteria for choosing particular technologies by synthesising the scientific literature on smart farming and doing a methodical examination.

The following is a description of the study's research framework. By locating study articles in the field, Section II explains the research methods utilised to comprehend smart agricultural solutions. The architectural components—including sensor types, automated actuators, gateways, power supply, networking, data storage, data processing, and information delivery—are then described and categorised in Section III. Building on this framework, Section IV examines patterns in the smart farming components categorised in the preceding section. In Section V, variables are highlighted for evaluation when selecting a component according to the classification described in this study. Lastly, the study's conclusions are presented in Section VI.

II. RESEARCH METHODOLOGY

In order to comprehend the technology used in smart agricultural solutions and the related data in the field, this research article takes an organised method that combines research action and a systematic review. The goal of the study is to clarify and present a comprehensive overview of the technologies and developments they bring for the realisation of full ground-level architectures and systems.

The paper is generated in three stages, which are the Plan Phase, the Perform Review Phase, and the Report Results Phase, using a semi-cyclic research methodology. During the Plan Phase, digital repositories and search parameters are

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designed to collect thorough data. Adapting search strings, gathering preliminary results, and choosing pertinent papers are the main objectives of the Perform Review Phase. Finally, the findings from the study approach are addressed in the Report Results Phase, which is followed by an analysis and discussion of the data.

A. PLAN PHASE

The purpose of this phase is to specify the instruments that will obtain the data required to initiate the research process. This approach began with the formulation of the following research questions.:

• Which features are most frequently utilised in practical smart farming applications?

• Which data treatment methods and parts are most frequently used in smart farming?

The ideas required for this work to be a literature review covering the finest smart farming designs, their components, software, and data treatment are summarised in these questions. We first determined the keywords for a methodical search of pertinent literature in order to answer the study topic. Among the terms that were selected were "smart farming," "IoT," "sensors," "network," and "wireless." Our initial search was based on these terms and the relevant connectors. Nonetheless, the first search produced an astounding amount of results, illustrating the wide range of tools and systems connected to smart agricultural solutions.

We eliminated phrases like "aerial," "CNN," "survey," and "protocol" in order to focus our search and better match the findings with our study goals. In order to concentrate on articles that offer thorough insights into ground-level designs rather than discrete investigations of particular components, several exclusions were made. Additionally, excluding terms like ‘‘aerial’’ helped filter out large IoT devices such as drones and robots, which were not the primary focus of our investigation.

Numerous scientific databases, including IEEE Xplore, Science Direct, and the ACM Digital Library, contained these keywords. Table 1 displays the search queries.1.

B. PERFORM REVIEW PHASE

The aforementioned digital databases were explored in this step using specific search strings that were determined in the previous stage. Our attention was focused on new solutions that were put out after 2018 as a result of these investigations. This emphasis is justified by the speed at which technology is developing, which means that within five years, new developments will render outdated solutions less effective. Therefore, giving contemporary research top priority enables us to evaluate the most recent advancements and remain abreast of the industry's technological frontiers..

After the search of previous works, an application called ‘‘Rayyan’’ was utilized for the classification process, whereby the .bib files attained from each digital repository were compiled. These files contain all the papers that match

TABLE 1. IEEE Xplore Digital Library, ScienceDirect and ACM Digital Library search results.

IEEE Xplore Di	
Search Strin	**Results**
("All Metadata":"smart farming") ANI data":iot) AND ("All Metadata":sensor Metadata":network) AND ("All Meta) NOT ("All Metadata":aereal) NOT data":CNN) NOT ("All Metadata":S ("All Metadata":"protocol")	92
Science Dire	
Search Strin	**Results**
("smart farming") AND (iot) AND (s (network) AND (wireless) NOT (aereal NOT (Survey) NO	45
ACM Digital	
Search Strin	**Results**
[All: "smart farming"]AND[All: sensors]AND[All: network]AND[All: NOT[All: aereal]AND NOT[All: cnn]A survey]AND NOT[All: "prot Publication Date: (01/01/2018TO12/31	17

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the search parameters in a certain database. The categorisation technique was made easier with the help of Rayyan's functionality, which emphasised each paper's pertinent information, such as the title, abstract, and keywords.
In the end, the procedure required a painstaking manual process. This involved carefully examining the abstracts and titles of papers that were collected from various online databases. Each paper was evaluated individually based on its abstract to determine its suitability for the research. The process's objective was to find any terms or expressions that might be used to assess the articles' applicability and relevance in addressing the suggested research issues. Papers were rejected if relevant material could not be located and if terms were absent. In this way, each of the remaining papers was evaluated separately to see how well it fit the research topic. Figure provides an illustration of the discard protocol in practice. 1.

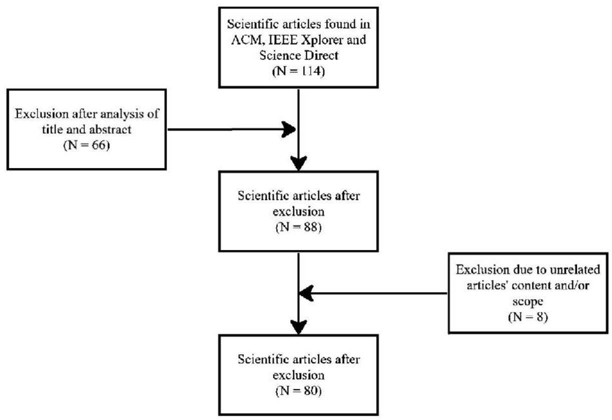

FIGURE 1. Paper reduction process.

This process encountered several challenges and com- plexities, necessitating resolution through virtual meetings among the responsible team members. During these sessions, Every member expressed their reasons for or against inclusion during the democratic evaluation of the items. By settling disputes and coming to a consensus on the papers' classification through this collaborative process, a thorough and well-organised selection process was guaranteed.

C. REPORT RESULTS

All of the collected results and findings were painstakingly recorded and arranged at this last stage. The following section, which forms the main body of this study article, was built upon these insightful observations. In order to detect significant trends and patterns regarding the use of technology components in smart farming, including crop solutions, the additional data were also thoroughly examined and discussed. This study aims to cover a wide range of technologies used for analysing the kinds of data that hold relevance in this sector by closely studying and interpreting these findings.

III. SMART FARMING SOLUTIONS

Innovative methods of farming have been made possible in recent years by the use of technology into agriculture. One such development is smart farming, a paradigm that uses state-of-the-art technologies to improve agricultural operations' production, sustainability, and efficiency. Using strategically placed sensor technologies, smart farming primarily enables farmers to carefully monitor and regulate a variety of environmental parameters, including soil moisture content, ambient temperature and humidity, and other significant aspects. There is a great deal of opportunity to improve the sustainability and effectiveness of agricultural production methods with this fine-grained level of environmental management.
Smart Farming implementation involves several key com- ponents, which collectively form a sophisticated ecosystem. Key components include sensor types, gateways, power supply, data storage, data analysis and processing, and information delivery, which lands in the Internet of Things (IoT), sensor networks, wireless connectivity, and even machine learning technologies. Each of them plays a crucial role in creating a comprehensive system.

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The following analysis provides a thorough review of the state-of-the-art in smart farming technology by exploring the literature to comprehend the developments, difficulties, and best practices within the framework of earlier research. With this investigation, we hope to clarify the various aspects of smart farming technology. By breaking down and assessing each element, we hope to add insightful information to the continuing discussion on agricultural practice optimisation through technology innovation.

For a thorough analysis of real-world uses and successful case studies in the application of smart farming

A. TYPES OF SENSORS

Smart Farming has established itself as a revolutionary approach in agriculture, leveraging technology to enhance crop production and optimize resource management. At the heart of this transformation lies the incorporation of sensors, which act as the eyes and ears of smart farming operations. These devices collect real-time data on various environmental parameters, providing farmers with a comprehensive understanding of their fields and crops. Sensors collect data about the agricultural environment. This data is used to feed smart farming systems, which can help farmers make more informed decisions about crop management. Among the different type of sensors for smart farming, the most commons are those created to measure air temperature, air humidity, soil temperature, soil moisture, ambient light, air quality, water level, combustible gas, pH, combustible gas, among others. For example, by monitoring soil moisture, air temperature, air humidity, water level, light intensity, and combustible gas, the scientific article referred to in [11] ensures optimal conditions for crop growth and resource management. Table 2 presents a concise overview of the sensors employed in the reviewed articles. The table is structured as follows: the left column contains the list of the type of sensors, while the right column shows the scientific articles in which these sensors are used or mentioned.

A. AUTOMATED ACTUATORS

To maximise crop health and resource use, some smart farming solutions also use automated actuators, such as water pumps, UAVs, and relays. For instance, systems that use water pumps for automated irrigation and relays to regulate greenhouse illumination are mentioned in [12]. The use of UAVs for agricultural monitoring and early disease or pest identification is also mentioned. A brief summary of the actuators and devices used in the examined studies is provided in Table 3. The structure of the table is as follows: A list of all automated actuators is shown in the left column, and the reviewed scientific publication that uses or mentions these electrical devices is displayed in the right column.

C. GATEWAYS AND EDGE DEVICES

Gateways act as go-betweens between end devices (like sensors or actuators) and networks, whether they are public or private (like the Internet). They make it easier for data to go between sensors and servers or between servers and actuators [13]. It's important to distinguish between gateways and end devices when thinking about smart farming infrastructures. End devices that are in charge of gathering data from the field or managing agricultural processes include Arduino, ESP32, NodeMCU, P89V51RD2 microcontroller, ESP8266, Arm Cortex-A Board, and Libelium

Dew point
Mist pump

TABLE 2. Different type of sensors used in previous works.

Type of Sens	Article Scientific Reviewed
Soil temperat	[8], [9], [10], [11], [12], [16], [20], [21], [24], [31], [38], [39], [40], [44], [45], [46], [51], [52], [63], [66], [68], [69], [70], [73], [76], [80], [82], [83], [85]
Soil moisture	[8], [9], [11], [14], [15], [16], [17], [18], [19], [20], [21], [24], [28], [29], [30], [35], [39], [40], [42], [44], [45], [46], [48], [49], [50], [52], [53], [54], [55], [58], [60], [61], [63], [64], [65], [66], [68], [70], [73], [74], [76], [77], [80], [82], [83], [85], [86], [87]
Ambient light	[9], [14], [17], [18], [19], [23], [24], [31], [35], [36], [38], [39], [52], [57], [58], [65], [66], [68], [71], [73], [80], [87], [88]
Air quality	[8], [9], [19], [23], [39], [46], [71]

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Ultrasonic	[47], [50], [60], [63], [71], [77]
PIR (Motion)	[46], [47], [71], [74], [77]
Humidity (DH	[8], [9], [10], [11], [12], [16], [17], [19], [20], [21], [23], [24], [28], [29], [38], [39], [40], [42], [45], [46], [47], [48], [49], [50], [51], [55], [61], [65], [71], [73], [74], [75], [76], [77], [79], [80], [82], [85], [86], [87], [88]
Sound	[20]
Air temperatu	[8], [14], [15], [17], [19], [20], [21], [23], [28], [29], [30], [31], [32], [35], [36], [42], [47], [48], [49], [54], [55], [56], [57], [58], [59], [60], [61], [62], [64], [65], [66], [67], [68], [69], [70], [71], [77], [79], [88]
Air humidity	[14], [17], [18], [20], [21], [23], [24], [30], [31], [32], [35], [36], [42], [46], [50], [51], [54], [56], [57], [58], [59], [60], [61], [62], [64], [65], [67], [68], [69], [70], [71], [85], [87], [88]
Water level	[17], [20], [38], [47], [67], [69], [70], [71], [74], [85]
Combustible (	[42], [47], [75]
Ldr	[20], [23], [24], [47], [65], [75]
Atmospheric ;	[9], [14], [16], [17], [19], [35], [39], [46], [58], [59], [64], [66], [76], [82]
Leaf moisture	[35]
Precipitation	[4], [15], [17], [26], [35], [59], [64], [66], [69], [70]
Soil oxygen	[35]
Wind speed	[17], [26], [35], [64], [66], [69], [70]
Wind directio	[15], [26], [35], [66], [69], [70]
AO3	[15], [25], [26], [44], [53], [63], [66]
	[36]
	[31]
Smog	[46], [56]
Electrical con	[58]
Soil NPK	[58]
pH	[40], [45], [58], [86]
Optical	[58]
Leaf wetness	[58]
Speed of wind	[58]
Flame	[77]

directly. On the other hand, gateways, exemplified by Raspberry Pi act as communication hubs, aggregating data from multiple end devices and transmitting it to the network. When selecting the appropriate gateway device for a smart farming architecture, various factors must be considered, including the number of connecting devices and communication protocols. The chosen gateway plays an important role in smart farming systems, which call for the ability to incorporate new technology without creating communication or informational problems. This skill is necessary for the seamless and effective expansion of the system.

Furthermore, gateways' efficacy depends on how well they work with the selected data management architecture. In order to ensure effective and unified data management throughout the whole smart agricultural infrastructure, they should competently support the architecture's data supply and reception mechanisms.

TABLE 3. Electronic actuators and devices used in previous works.

Electronic De	Scientific Article Reviewed
Camera	[16], [39], [42], [44], [56], [65], [82], [83]
Buzzer	[16], [21], [44], [46], [71], [75]
Relay	[16], [17], [18], [28], [30], [44], [70], [71], [81], [88]
Flashlight	[44], [53]
Water pump	[10], [15], [16], [17], [18], [21], [28], [30], [38], [46], [47], [49], [52], [53], [58], [61], [62], [64], [70], [71], [78], [81], [88]
UAV	[83]

Numerous research use open-source, reasonably priced tools to create gateways and end devices. Using their ability to read sensor data and carry out predetermined actions, Arduino, ESP32, NodeMCU, P89V51RD2 micro-controller, ESP8266, Arm Cortex-A Board, and Libelium become well-liked options for smart farming end products [13]. In some configurations, especially those that use a 6LoWPAN-based WSN configuration, Raspberry Pi are used as gateway nodes [14]. In this regard, the gateways guarantee smooth communication with network servers and make it easier to aggregate data from end devices.

The use of both gateways and end devices demonstrates a trend towards the development of smart agricultural applications using open-source, reasonably priced solutions. These tools are well known for meeting the various demands of agricultural technology due to their adaptability and scalability. Table 4 shows how prevalent these gadgets are in smart farming applications and how they may be tailored to meet different needs. Additionally, each device's unique areas of specialisation are displayed in the table, which reflects the careful considerations designers made to customise smart farming solutions to certain objectives and applications.

D. POWER SUPPLY

Smart farming requires installed devices nearby crops. These devices need a reliable and efficient power supply to operate. Due to the expansive nature of agricultural crops, the provision of continuous electrical power via traditional electrical cables is not feasible. Considering this scenario, the importance of portable electrical power sources choice becomes crucial. Table 5 shows battery types discussed in the reviewed articles. Some of the most used power supplies include AA, AAA, 9V and lithium-ion type batteries (LiPo and LiFePO4 mainly), but some solutions also use solar panels and external or internal/on-device power supply units

AA battery
9V battery

TABLE 4. Gateways and edge devices used in previous works.

Networking	Scientific Article Reviewed
Arduino	[4], [9], [16], [17], [20], [21], [25], [27], [30], [36], [37], [38], [39], [40], [43], [47], [50], [51], [60], [61], [62], [65], [70], [75], [76], [77], [78], [81], [82], [84]
Raspberry P	[14], [16], [20], [22], [23], [34], [42], [56], [57], [58], [59], [60], [61], [63], [64], [65], [66], [68], [69], [71], [72], [73], [74]], [80]
ESP32	[9], [11], [12], [18], [28], [53], [54]
Arm Cortex-	[44], [67]
P89V51RD2 micr	[45]
ESP8266	[16], [18], [20], [21], [29], [30], [46], [49], [52], [65], [71], [89]
Libelium	[32]

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TABLE 5. Power supply solutions used in previous works.

Power Supp	Scientific Article Reviewed
Battery, Pill	[29], [27], [47], [33], [49], [50], [54], [40], [16], [56], [57], [58], [59], [21], [42], [61], [62], [73], [63], [30], [17], [64], [15], [65], [22], [66], [67], [23], [68], [69], [18], [70], [20], [71], [72], [10], [43], [37], [9], [39], [80], [81], [82], [83]
Computer, L	[25], [45], [53], [40], [16], [56], [57], [58], [59], [21], [42], [61], [62], [73], [63], [30], [17], [64], [15], [67], [23], [68], [69], [70], [20], [71], [76]
Power Suppl	[44], [40], [16], [56], [57], [58], [59], [21], [42], [61], [62], [73], [63], [30], [17], [64], [15], [66], [67], [23], [68], [69], [70], [20], [71]
Solar panel, s solar radiatioı	[27], [47], [33], [48], [49], [40], [42], [73], [17], [18], [70], [20], [72], [74], [43], [35], [9], [8]
Power line	[54], [75], [76], [4], [88]
AA battery	[21]
LiPO, LiFeP	[28], [20]
	[89]
	[70]
Not mention	[46], [34], [14], [53], [55], [40], [60], [61], [62], [73], [63], [64], [65], [22], [66], [23], [68], [69], [20], [71], [72], [12], [11], [38], [77], [36], [78], [84], [85], [86], [87]

Just a small part of covered literature refers to power supplies as specified batteries, solar panels, and fuel cells. For example, in [15] an autonomous gardening rover (quadrotor UAV) with plant recognition was built using neural networks. They relied on a 12V, 7Ah battery to power the rover, which could run for about 2 hours (autonomy time). They plead that solar panels could be used to extend and fill the battery life once it lacks, however there was no basic explanation at all comprising energy plans or their structure.

Problem solvers frequently prioritize practicality over addressing specific issues when prototyping solutions. Non-commercial solutions often lack sophistication in their assembling. In contrast to using commonly specified batteries or power supply units (PSUs), researchers typically treat their solution systems as modules that are attached to or housed within local, non-portable hardware (such as computers or controllers that are directly plugged into wall outlets). Projects that have not yet advanced to the production stage could be the cause of this trend. n [16], for example, a Raspberry Pi 3 (CPU), an Arduino UNO R3, a Node MCU ESP8266 (controllers), and a few periferics (fans, sensors, cameras, etc.) were powered by a 12 V PSU in order to create a system for data processing and transmission for a "Agri-IoT" framework. On the other hand, in their suggested irrigation systems, [17] and [18] used solar panels as their energy source. These panels were designed to enable the deployment of sensor nodes in remote locations, hence lowering maintenance costs. One of these uses a 10 W, 12 V polycrystalline solar panel to charge 12 V, 7 Ah rechargeable batteries. Now, a LiFePO4 battery was used to power the sensors and actuators in an IoT-based agricultural system [19]. In comparison to lead-acid batteries, they discovered that this battery type delivers a higher energy density and a longer lifespan. On the other hand, [20] described how a LiPO battery is required in order to build a flexible transportable multi-sensor unit with open-source hardware platforms. Furthermore, literature shows that solutions are based on the physical principle of relays, which means that in order to achieve integral system functionality (four AAA batteries in this case), they usually require both an AC connection and a DC battery connection. A stable automated monitoring and environmental control system for laboratory-scale growth was implemented in [21] using two relays for air pumping and cooling fan control. These days, sophisticated smart farming

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solutions come with smart/industrial machinery, including robots that can perform chores like weeding, spraying, planting, and harvesting. In reference to high-speed information transfer, [22] talks about how machines and robots need durable power sources for both effective data sharing and movement and operation. In order to overcome obstacles, recent initiatives seek to organise data, increase productivity, and strengthen decision-making [23]. Data loads need to be processed quickly in order for actuators to carry out everyday duties in the real world and for the system to successfully exhibit real-time operations. Even the most advanced rovers or drones, however, are typically unable to outperform farmers in all-day work. Finding a convincing balance between a device's performance and battery life is still a problem that has to be solved and tested extensively.

E. NETWORKING

Communication protocols at the medium access control, network, and application layers have been designed aiming to optimize data rate and allow large amounts of information to be transmitted efficiently, over reliable connections with min- imal transmission errors [24]. Communication technology is key to ensuring compatibility, security, scalability, and efficiency, enabling the seamless integration of various devices and technologies to optimize agricultural processes. The efficient implementation of a smart farming solution requires flexibility in arranging sensors placed across varied distances within the smart agriculture system. These sensors, positioned both near and far from each other as well as from the central gateway, correspond to the diverse spatial zones covered by monitored crops. The number of sensors deployed relies not only upon the physical area but also on the specific parameters considered in crop analysis. Consequently, the communication infrastructure must support a range of data types and hardware, enabling their seamless integration into a unified gateway. The continuous transmission of crop status updates is an important aspect of the significance of a reliable communication system. Finally, as agricultural architecture evolves, scalability becomes critical. The communication framework should facilitate the integration of new devices, offering an efficient and user-friendly connectivity solution for the farmer.

In short, the acquisition of communication technology is important it can fulfill requirements on three metrics: energy efficiency, coverage, and scalability [13].

Several solutions have employed distinct communication technologies tailored to specific needs. For instance, in [25] and [26], a Wi-Fi model facilitates data transmission to the cloud for subsequent analysis. Conversely, the solution proposed in [27] utilizes Zigbee due to its capacity to interconnect numerous nodes (up to hundreds) and transmit over considerable distances of up to 120 meters in line of sight. Another solution employs LoRaWAN as its primary communication technology, leveraging its wide coverage, extensive range, low power consumption, cost-effectiveness, and satisfactory transmission rate, particularly suitable for telemetry data [28].

Table 6 contains a list of communication papers and the papers in which they are used respectively.

According to the results, the most used technologies in the architectures are Wi-Fi, and Bluetooth, which are traditional protocols, this can be related to the fact that they have been in the market for a long time and can be widely accessible, contrary to new technologies that may take time to find their way to a bigger audience. But it can also be noted that the protocol's range is diverse, showcasing the variability of the conditions between the solutions of smart farming, therefore a different type of protocol is chosen to fulfill its necessities.

F. DATA STORAGE

Cloud-based smart farming solutions platforms are one of the most used options to store and process the data collected from sensors and devices. A smart hydroponics system that automates the growing process of the crops using Bayesian Network (BN) model [15], uses Google Firebase as cloud storage service. Similarly, using Google Sheets (a web- based spreadsheet app from the Google Docs Editor suite), [16] delivers data gathered from the analog channel of an

TABLE 6. Gateways and edge devices used in previous works.

Communica tocol	Scientific Article Reviewed
Cellular net	[29], [30], [33], [36], [53], [81]

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Wi-Fi	[4], [9], [15], [16], [18], [20], [21], [25], [26], [29], [30], [33], [36], [40], [42], [46], [47], [48], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [65], [66], [70], [71], [72], [73], [74], [75], [78], [84], [88]
LoraWAN	[8], [28], [35], [39], [53], [67], [72], [76], [78], [82], [83], [89]
GSM	[17], [30], [45], [71]
Zigbee	[8], [12], [17], [27], [40], [53], [67], [71], [74], [77]
MQTT	[10], [12], [16], [37], [43], [49], [64], [75], [80], [75]
UHF	[50]
ISM	[50], [67], [73]
GPS	[16], [20], [22], [40], [51], [55], [58], [62], [68], [78]
6LoWPAN	[14], [73]
Radio wave	[53]
Bluetooth	[16], [18], [21], [23], [40], [42], [53], [54], [56], [57], [58], [59], [60], [61], [64], [66], [69], [70], [73], [78], [84]

Arduino UNO controller through the Node MCU ESP8266 controller. Cloud-based data storage offers advantages such as scalability, accessibility, and security.

Additionally, there are also IoT cloud platforms that store and process the data collected from IoT devices. Revisiting [15], the use of ThingSpeak as an IoT cloud platform to store and visualize the sensor data is helpful when building self-sustainable agricultural production through data analytics. Similarly, [29], designed and implemented a connected smart farming system that uses Blynk server as an IoT cloud platform to store and control the sensor data.

Both, ‘‘regular’’ cloud-based and IoT cloud-based data storage offers advantages such as real-time data processing, remote monitoring, and event detection for smart farming solutions.

Another alternative was to store the data gathered from sensors and devices on local storage devices such SD cards, USB drives, or local PCs that use HDD or SSD drives. An Android application created in [30] to save the logs of a smart autonomous gardening vehicle with neural network-based plant recognition takes data from the on-board sensors and stores it directly on the internal device storage (SD card use is presumed). Similar to this, the data collected by the sensor nodes is stored on a local computer in the design and deployment of an IoT system for span greenhouse agriculture in [31]. Benefits of local data storage for smart agricultural solutions include affordability, ease of use, and privacy.

Again, everything depends on what the context is and what scope researchers want to have with the information generated. Even though data is the main concern in this subtopic, it is important to understand that most of the times designers will prefer a centralized solution, i.e. a place or service where the smart farming solution can be deployed and the data gathered can be processed as well; hence, it is possible to have almost total control.

Table 7 provides an overview of previous paragraphs. Cloud and local (computer) storage are the most preferred data storage solutions. For sure, a combination of both will provide a secure way to handle data given the high availability and continuous synchronization of information.

TABLE 7. Data Storage solutions used in previous works.

Data Storag	Scientific Article Reviewed
Generic clou	[14], [53], [54], [55], [40], [16], [56], [60], [21], [42], [62], [73], [63], [30], [17], [64], [15], [65], [22], [66], [67], [23], [68], [18], [70], [20], [71], [74], [12], [76], [39], [85]

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Generic computer s	[45], [16], [56], [57], [58], [59], [60], [21], [42], [61], [62], [73], [63], [30], [17], [64], [15], [65], [66], [67], [23], [68], [69], [70], [20], [71], [72], [9], [36], [80]
ThingSpeak	[26], [25], [47], [48], [34], [21], [15], [18], [38], [78], [81], [4]
IoT Cloud	[46], [16], [21], [73], [64], [65], [23], [18], [77], [82], [83], [88], [8]
Firebase	[51], [21], [15], [10], [43], [89]
MySQL	[33], [62], [71], [11], [37], [84]
Google Driv	[63], [75]
Blynk	[29], [47]
Generic SD	[44], [20]
Node-RED	[49]
The Things !	[28]
Adafruit	[52]
Not mentior	[50], [61], [64], [15], [65], [69], [72], [35], [86], [87]

G. DATA PROCESSING

Reduced food production often stems from various fac- tors, such as inadequate planning, unpredictable weather conditions, improper harvesting and irrigation techniques, and livestock mismanagement [32]. In addressing these challenges, technology emerges as a crucial factor by harnessing extensive information through sensors and cli- matic records. This data is instrumental in understanding plant needs and environmental conditions, enabling the precise allocation of resources like water and minerals. Consequently, this enhances the overall health of the system, mitigates challenges faced by farmers, and significantly reduces the reliance on fertilizers and chemicals [32]. These technological advancements, rooted in effective data processing, lead to sustainable practices, minimize waste, and elevate efficiency within the agricultural process.

The current investigation recognizes three primary domains for data processing in smart farming: artificial intelligence (AI) serves as the overarching category, threshold-based data analysis, and manual determination as shown in Table 8. In this context, [33] exemplifies the integration of cloud-based ML algorithms analyzing drone-captured images to identify vine diseases, highlighting ML as an integral component of the broader AI framework. Similarly, [34] leverages AI, specifically a neural network, to predict greenhouse air temperatures. Despite the diverse applications of AI and ML, some farmers persist in employing threshold-based data approaches to set operational conditions [26], while others rely solely on statistical information presented in dashboards derived from collected data, lacking the advanced decision-making capabilities inherent in AI systems [35].

TABLE 8. Gateways and edge devices used in previous works.

Data proces	Scientific Article Reviewed
IA	[4], [8], [9], [15], [16], [17], [21], [22], [23], [30], [33], [34], [38], [42], [43], [52], [54], [57], [58], [59], [60], [61], [63], [64], [65], [66], [68], [69], [70], [72], [73], [74], [82], [83], [84], [85], [86], [87]
Threshold-b data	[15], [16], [25], [26], [28], [30], [42], [44], [45], [46], [47], [49], [51], [53], [56], [63], [70], [71]
Manual cont	[11], [15], [35], [36], [37], [39], [49], [51], [56], [61], [65], [75], [78], [80], [81], [88], [89]

Manual interpretation in data processing involves the human-driven analysis and comprehension of information without relying on automated algorithms or computational models. In this context, individuals, often experts or domain

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specialists, inspect and make sense of raw data, identifying patterns, anomalies, or specific insights that may not be easily discernible through automated means. This hands-on approach allows for a qualitative understanding of the data, drawing on human expertise, intuition, and contextual knowledge to extract meaningful information.

H. INFORMATION DELIVERY

The presentation of monitoring information to farmers or users is an important consideration in smart farming systems. This is because the information can be presented through a variety of channels, such as web platforms, mobile platforms, text messages, desk application, etc. The different channels for presenting information have their own advantages and disadvantages. Web platforms offer a wide range of features and capabilities, but they can be difficult to use for users who are not familiar with technology. Mobile platforms are easier to use and more accessible, but they may have limitations in terms of functionality. Text messages are the simplest and most accessible form of presentation, but they are also the least flexible. The choice of the right channel for presenting information depends on several factors, such as the needs of the farmer or user, the type of information being presented, and the available budget. Table 9 presents a concise overview of the different ways to display information utilized in the reviewed articles. The table is structured as follows: the left column contains a list of all ways to display information, while the right column shows the scientific article reviewed in which these information deliveries are the subject of study.

TABLE 9. Ways to display information used in previous works.

Information	Scientific Article Reviewed
Mobile app	[4], [8], [22], [26], [29], [30], [37], [40], [43], [46], [47], [49], [51], [53], [54], [55], [57], [58], [62], [74], [75], [83], [84], [85], [88]
Webpage	[8], [9], [10], [11], [15], [16], [17], [18], [20], [23], [25], [38], [40], [46], [47], [52], [53], [60], [62], [64], [71], [76], [77], [78], [80], [83], [85], [86], [88], [89]
Email	[16], [25], [30], [62]
Message	[17], [21], [30], [35], [38], [44], [45], [53], [62], [71]
Desk applicatic	[15], [21], [30], [33], [40], [42], [44], [45], [56], [59], [61], [63], [65], [66], [67], [69], [70], [73]
Thing Speak A	[18], [21], [48], [49], [78]
Cloud Platforn	[39], [81]
None	[12], [14], [20], [23], [27], [28], [40], [42], [59], [61], [62], [63], [64], [66], [67], [68], [69], [70], [72], [82], [87]

IV. DISCUSSION

A. SENSORS

Figure 2 clearly demonstrates that a vast majority of authors prefer the implementation of multiple sensors for effective control in smart farms. The Soil Moisture sensor is particularly prominent, with fifty mentions in the reviewed architectures. This indicates the significance of measuring soil moisture to understand plant growth conditions. According to study [9], soil temperature is a crucial factor affecting seed germination, root development, and nutrient availability, all of which are essential for determining the optimal watering times. The use of the Soil Moisture sensor enables more precise and effective irrigation, thus improving the quality and yield of crops, as outlined in [36]. Closely following are two closely related sensors, the Air Temperature sensor, and the Air Humidity sensor, with 42 and 36 appearances, respectively. Their importance lies in the fact that temperature and humidity are critical environmental parameters that directly impact plant growth and health. Temperature influences photosynthesis, respiration, and transpiration, while humidity affects water and nutrient absorption. As per [36], the joint measurement of both variables allows for comprehensive monitoring of environmental conditions, facilitates the identification of plant stress, and enables precise decision-making to adjust irrigation, ventilation, and other factors. With twenty-eight mentions, the Soil Temperature sensor plays a significant role. According to the scientific article cited in [12], monitoring soil temperature is vital for optimizing plant growth, as it affects seed germination, nutrient absorption, and soil microbial activity. With

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twenty-four mentions, the Ambient Light sensor is crucial for measuring water flow in irrigation systems, key in controlling water supply to the plants, as mentioned in [37]. Beyond the sensors mentioned,

Figure 2 presents a wide array of additional tools used by researchers.

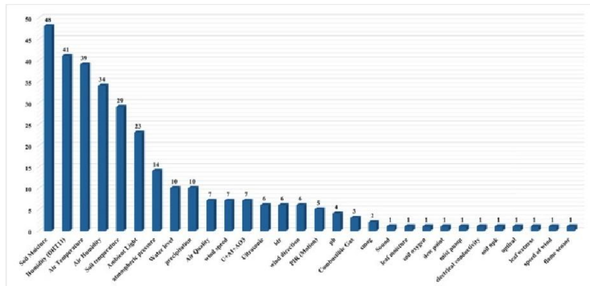

FIGURE 2. Sensors used in the reviewed research.

B. AUTOMATED ACTUATORS

Figure 3 indicates a clear preference among authors for the use of specific actuators and electronic devices in the efficient management of farm resources. The water pump is particularly noteworthy, being mentioned 24 times in the analyzed architectures. According to the research [10], the main benefit of using water pumps for crop irrigation is their ability to optimize water usage. Through continuous monitoring of temperature and humidity, the system can adjust irrigation to specific areas as needed, avoiding over-watering in already moist areas, thereby enhancing water usage efficiency. Relays, cited in 11 instances, play a key role in regulating power supply to devices like water pumps. The study [37] emphasizes that using relays allows for more precise control of electronic devices and improves the system's energy efficiency. Furthermore, as noted in [38], relays enable the automation of processes such as irrigation, adapting to environmental and soil conditions, leading to improved crop efficiency, and reducing the need for human intervention. On the other hand, cameras, mentioned 8 times in the review, are highlighted in [39] for their effectiveness in monitoring the presence of fruits in the field, essential for efficient crop management and informed decision-making in precision agriculture. Figure 3 expands the view on a variety of actuators and electronic devices used by researchers to deepen their analyses.

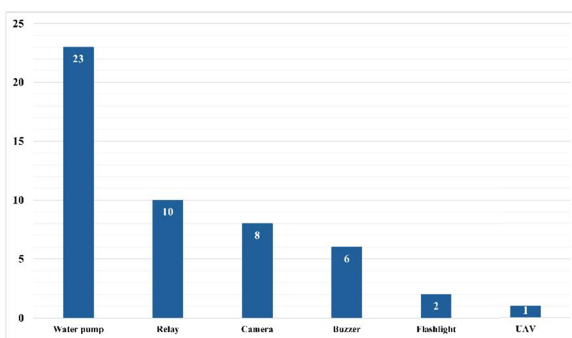

FIGURE 3. Automated actuators used in previous works.

C. ATEWAYS AND EDGE DEVICES

As depicted in Figure 4, given the specified percentages, Raspberry Pi stands out as the most commonly used gateway, being present in 25.3% of the examined architectures.

Among end devices, Arduino has the highest usage percentage at 32.9%, indicating its widespread adoption in smart farming applications. This prevalence suggests that factors such as the extensive community support, flexibility, and user-friendly nature of Arduino have played pivotal roles in end device selection. Arduino's adaptability in interfacing with a diverse array of sensors commonly employed in smart farming further enhances its appeal as an end device, ESP32 and NodeMCU follow with equal usage percentages of 7.7%. this may be due to being chosen for smart farming

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applica- tions due to their integrated Wi-Fi capabilities, compatibility with various sensors, cost-effectiveness, community support, and flexibility in programming. The percentages for the Arm Cortex-A Board, P89V51RD2 micro-controller, and Libelium are significantly lower compared to other devices. Their inclusion in the spectrum of devices used reflects the diversity in technological choices made by researchers to address specific requirements and challenges in smart farming applications.

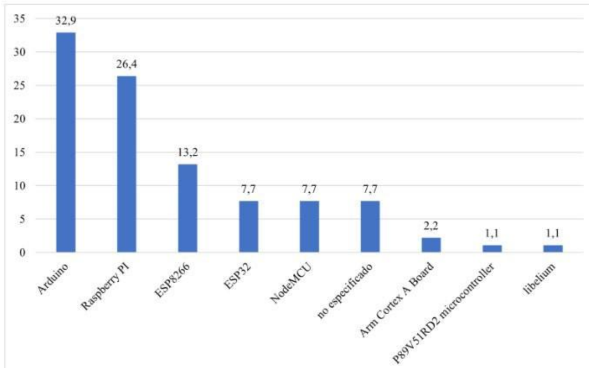

FIGURE 4. Gateways and end devices used in previous works.

Given the predominantly academic nature of the stud- ies reviewed, many smart farming solutions focused on smaller-scale implementations that didn't require extensive gateway infrastructure. Consequently, there is a noticeable lack of emphasis on gateways in the papers examined. This trend underscores the importance of versatile and adaptable end devices like Arduino, ESP32, and NodeMCU, which were frequently utilized to meet the needs of these smaller- scale applications.

D. POWER SUPPLY

The Power Supply Type (PST) classification approach holds significant relevance for researchers, designers, engineers, and farmers in the realm of smart farming. It serves as an initial framework for understanding the diverse array of power supply options, along with their respective advantages and disadvantages, supported by real-world, long-term use cases. This approach helps with the development, design, installation, maintenance, and utilization of proof-of-concept solutions, all of which are aimed at enhancing existing farming methodologies and systems.

Batteries and pills were frequently referenced terms in PST discussions, appearing 45 times. Computers and laptops, which encompass both external and internal power supply units (PSUs) housed within desktop or laptop chassis, were mentioned 28 times. Surprisingly, in 31 instances, there was no mention of how power supply issues were addressed.

The prevalence of terms such as batteries and pills suggest their versatile meanings. These terms encompass various conventional small-scale power storage options, including AA, AAA, 9V, and LiPO / LiFePO4 batteries. They are chosen for their portability and utility, particularly in remote areas where access to grid power and maintenance schedules may be limited.

Some less commonly discussed terms related to power systems technology (PST) include Solar panels, Solar energy, PSUs, and various battery types such as AA, AAA, and 9 V; including LiPo and LiFePO4 varieties. Additionally, references to the Power line, denoting the wall outlet, are infrequently mentioned in this context. It is worth exploring the reasons behind the lesser prevalence of these terms – whether due to their lesser-known status, limited utilization, or reduced significance within the field.

Figure 5 provides a visual representation of the occurrence and distribution of these terms and associated topics, offering valuable insights into their relative importance and interrelationships within the PST domain.

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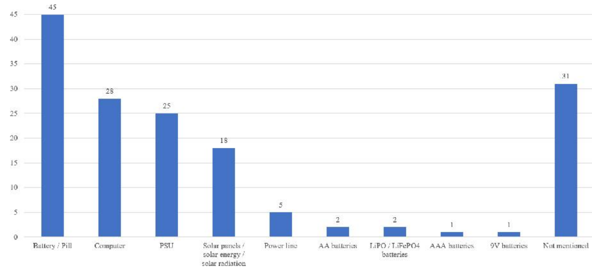

FIGURE 5. Preferred power supply types in smart farming solutions.

While solar energy presents an attractive option for areas lacking access to power lines, its effectiveness hinges on a robust energy storage system for uninterrupted power supply. Unfortunately, this critical aspect often remains inadequately addressed. PSUs face limitations due to their lack of portability and dependency on power lines, which restrict their utility in remote or mobile applications.

Traditional disposable batteries like AA, AAA, and 9 V are plagued by a limited lifespan, rendering them less viable compared to rechargeable alternatives such as LiPo and LiFePO4 batteries. Renowned for their durability and high energy density, these rechargeable options offer a more sustainable solution.

While power lines offer reliability, they are inaccessible in many common farming scenarios. Ultimately, the choice of power supply type depends on various factors, including the specific application, geographical location, power requirements, and associated costs. By addressing the complexities and trade-offs inherent in different power supply options, stakeholders can make more informed decisions to meet their energy needs effectively.

F. NETWORKING

In Figure 6, WiFi emerges as the primary communication protocol in the examined previous works, constituting 44% of the solutions, likely due to its widespread availability and high data transfer rate, particularly in small-scale smart farming applications. The familiarity of WiFi modules among researchers may also contribute to its popularity, facilitating easy wireless communication. However, WiFi's dominance may be influenced by its performance limitations in long-distance transmissions or remote areas. Following Figure 4 bluetooth follows WiFi in popularity, showing good performance for short-range solutions. However, it hasn't been as commonly selected for large-scale and scalable applications.

Overall, the prevalence of WiFi and Bluetooth as the main communication protocols can be attributed to the emphasis on small-scale smart farming applications in the research findings.

Other protocols, including LoRaWAN and Zigbee, account for 12% and 10% of usage, respectively. LoRaWAN exhibits superior adaptability to diverse and challenging environments. Furthermore, they boast long-range capabilities, which are particularly advantageous for large-scale smart farming architectures. Additionally, both LoRaWAN and Zigbee feature low-power characteristics, facilitating efficient data transmission over extended periods. It's worth noting, however, that Zigbee is not renowned for its long- range capabilities. Despite this limitation, its adaptability to various environments and low-power features make Zigbee a viable choice for specific smart farming applications where extended range may not be a critical requirement.

Other protocols, such as MQTT with a lesser percentage, provide a glimpse into the diverse usage cases addressed by the revised solutions. MQTT operates on a publish- subscribe model, facilitating time-sensitive applications that require real-time data processing and export. On the other hand, MQTT offers some architectures a robust solution for applications demanding real-time data processing and communication. Lastly, the protocols remaining encompass a wide spectrum, ranging from cellular networks (GSM), long-range wireless technologies (LoRaWAN, UHF, ISM), short-range communication (Bluetooth, Zigbee), positioning systems (GPS), to data representation and transmission (MQTT, 6LoWPAN).

The diverse range of communication protocols illustrated in Figure 6 signifies the absence of a standardized approach within the smart farming community when constructing such architectures. While this flexibility allows for tailoring solutions to specific architectural requirements, it also raises concerns about scalability and compatibility when integrating different systems. The absence of a universally adopted standard may lead to challenges in scalability and

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interoperability, emphasizing the importance of establishing common frameworks or guidelines within the smart farming domain to ensure seamless integration and scalability across various technological solutions.

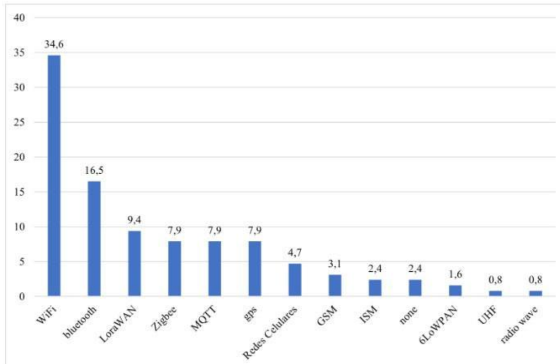

FIGURE 6. Network usage distribution.

G. DATA STORAGE

The choice of data storage depends on several factors, such as data volume, availability, accessibility, security, and cost. Among the data sto rage solutions observed in the smart farming scenarios studied, Computers and Laptops were the most common (30 occurrences), followed by ThingSpeak (12 occurrences), Cloud (10 occurrences), IoT Cloud (10 occur- rences), with an additional 10 occurrences where data storage method was not mentioned. This can likely be attributed to the versatility, ease of use, and affordability of modern computers, along with the specialized features offered by ThingSpeak software for IoT data storage and visualization. Additionally, cloud storage provides scalability, practicality, and security in a cost-effective manner.

While other data storage solutions such as Google Docs Editor suite, Firebase, MySQL, SD cards, Blynk Server, Node-RED, Things Stack Network Server, and Adafruit are less common, they offer unique advantages and disadvantages that may make them suitable for specific scenarios. For example, cloud-based solutions like Google Drive and Firebase offer remote accessibility and collaboration, while on-premises solutions like SD cards and computers provide greater control over data security and privacy. Ultimately, the choice of data storage solution should be carefully considered based on the specific requirements and constraints of each smart farming application; certainly, it often depends on the scalability of the project.

Figure 7 shows that local Computers and Laptops are among the most preferred solutions, being almost 50% of reviewed alternatives. This dominance may be because every farm has its own needs, i.e. they are local non-scalable proposals

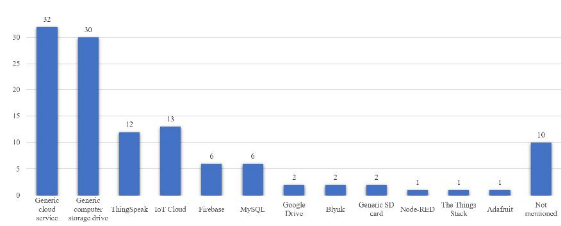

FIGURE 7. Preferred data storage types in smart farming solutions.

H. DATA PROCESSING

In Figure 8, the predominant methods in smart farming applications are collectively identified under the over- arching category of artificial intelligence (AI). Within this broader classification, the most prevalent techniques include machine learning (ML), which involves algorithmic approaches responsible for analyzing and interpreting data to autonomously respond to the status of crops or dictate necessary parameters for plant care. The use of AI, encapsu- lating ML, signifies a growing reliance on automated systems that leverage data-driven insights to optimize agricultural processes.

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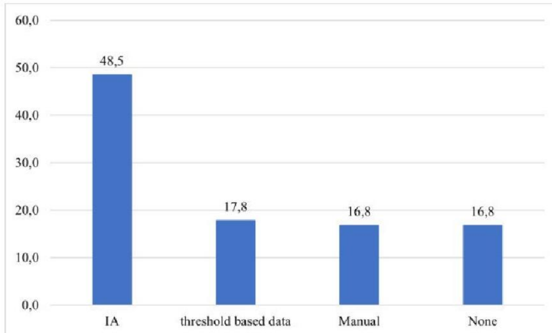

FIGURE 8. Data processing chart.

Some studies have specifically highlighted machine learning as a key component, potentially due to its more recognizable and widely understood term compared to the broader umbrella of artificial intelligence. This preference for emphasizing machine learning could stem from the specificity and clarity associated with ML methodologies, which involve the training of algorithms to learn patterns from data.

The second most adopted approach involves a simpler method of setting predefined limits for variables, triggering specific actions accordingly. While effective in stable envi- ronmental conditions, this approach may be limited when faced with diverse datasets, potentially impacting the required care for crops under new conditions.

The third approach incorporates direct human intervention, where analysis and responses from the system are obtained through data display, often in the form of dashboards. Unlike sensor-driven systems, many solutions in this category rely on human decisions for actions like water sprinkling, and alerting farmers through text or audio. While this approach may not optimize resource usage, it does contribute to maintaining control over plant health.

Figure 8 illustrates the distribution of data processing usage in smart farming solutions. This categorization underscores the diversity of priorities among designers, with some favoring sophisticated automated systems, others opting for simplicity and predefined triggers, and some relying on direct human involvement for decision-making. The juxtaposition of these approaches highlights the multifaceted nature of smart farming solutions and the need for a nuanced understanding of the varying degrees of autonomy and control within these systems.

I. INFORMATION DELIVERY

An essential aspect of smart farming solutions is how information is delivered to the user. To illustrate the most used ways to present information to the user, Figure 9 has been developed, based on the scientific articles reviewed.

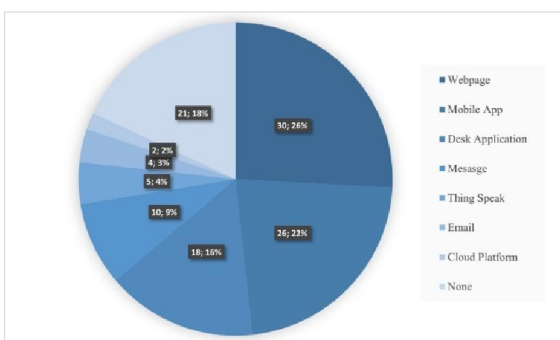

FIGURE 9. Effective methods for presenting information from research reviewed.

Figure 9 shows that 26% of the reviewed articles use a web application to present information to the user, while 22% use a mobile application. On the other hand, 18% do not specify the deployment type, while 16% use a desktop application, 9% use SMS messages, 4% use a Things Speak platform API, 3% use email, and finally, 2% use services provided by cloud platform. The popularity of certain solutions is primarily due to the convenience and accessibility they offer to users. For instance, web and mobile applications account for 48% of the solutions due to the increasing prevalence of mobile applications and the easy way for accessing information from any location. Desktop applications, which represent a smaller percentage than web and mobile applications at 16%, are still used by some users who prefer to work on more traditional platforms. On the other hand, SMS messaging is popular due to its simplicity and wide availability on mobile devices, making it a viable option for data communication in remote agricultural environments.

V. DEVICE SELECTION STRATEGY

A. SENSOR

In the design smart farming architecture, a diverse range of sensors is essential for gathering precise environmental data relevant to crop management decisions. The choice of sensors depends on the specific needs of the smart farming solution, focusing on collecting data vital for effective decision-making regarding crop yields. These sensors must seamlessly transmit data to the gateway without disrupt- ing other sensor functions or communications. To ensure farmers can focus on utilizing collected data rather than troubleshooting hardware issues, selected sensors should be adaptable across different architectures to meet these criteria and facilitate straightforward migration if infrastructure adjustments are required.

Reliable and precise sensors are crucial for high-quality data collection. It is important to maintain consistent precision and close alignment with actual values [9]. The assessment of sensors should include their measurement range and calibration to ensure accurate precision evaluation. Furthermore, sensors must be able to withstand various climatic and environmental conditions to accurately assess farm conditions. It is important to note that different sensor materials may perform differently under freezing or high temperatures, which can impact data accuracy or cause damage [37]. Hence, understanding the environment and the components and materials of the sensors is crucial for an extended architectural life cycle.

B. AUTOMATED ACTUATORS

Selecting automated actuators is vital for Smart Farming infrastructure as they convert control system signals into physical actions. Actuators serve as the backbone for automating critical agricultural processes such as activating irrigation systems, regulating greenhouse ventilation, and facilitating the operation of agricultural implements [10], thereby significantly enhancing operational efficiency within the farm environment.

In the realm of Smart Farming, a diverse array of actuators is employed, encompassing electric actuators and water pumps, among others. Notably, the utilization of water pumps is paramount for optimizing irrigation processes, ensuring precise delivery of water to crops at optimal intervals [12]. Similarly, the deployment of relays for controlling greenhouse lighting contributes to the creation of ideal growth conditions for plants, consequently augmenting both crop yield and quality. The selection criteria for actuators in Smart Farming include considerations such as reliability, durability (with adherence to IP67 standards), energy efficiency, compatibility with sensors and controllers, functionality for specific tasks like irrigation management, and ease of integration into the system.

C. GATEWAYS AND EDGE DEVICES

In the process of selecting options for gateways and end devices in smart farming applications, several key criteria should be carefully considered to ensure the effectiveness and compatibility of the chosen devices with the overall system. Firstly, it is essential to assess the functionality required for the specific smart farming application, whether it involves data collection from sensors, control of actu- ators, or serving as a communication hub. Compatibility is another critical factor, necessitating alignment between the selected devices and existing infrastructure, including sensors, communication protocols, and data management frameworks [13]. Scalability is paramount to accommodate future expansion or changes in the smart farming system, necessitating devices that can seamlessly integrate new technologies and support increased data volume over time. Evaluation of communication protocols supported by the devices is crucial, with considerations including Wi-Fi, Bluetooth, LoRaWAN, Zigbee, or cellular networks, based on application requirements and environmental conditions [13]. Cost-effectiveness plays a significant role, in balancing initial purchase costs, maintenance expenses, and potential future upgrades against required functionality and perfor- mance. Reliability is paramount in harsh agricultural envi- ronments, necessitating devices known for their durability, resistance to environmental factors, and long-term stability. Additionally, consideration of community support is essen- tial, with active communities providing valuable resources

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and assistance for troubleshooting and development [13].

Finally, ease of use is crucial for both developers and end-users, requiring devices with intuitive interfaces, comprehensive documentation, and straightforward setup processes.

D. POWER SUPPLY

Researchers' literature has shown that there is a lack of information regarding power supply choices. Overall, there are not common ways to approve or discard a specific power consumption device other than meeting minimum specifications that a given solution requires. Let us think about how sensors and actuators can function effectively, it is crucial to consider their energy consumption. Wireless sensors typically consume more energy than wired sensors; therefore, the use of an autonomous and sustainable energy source, such as solar energy, is recommended. In that way, [48] and [49] mention the use of solar-powered sensors. These autonomous devices offer greater flexibility and ease of installation compared to wired systems. Nevertheless, despite solving the energy consumption issue, they can be more expensive and complex to install.

Commonly revisited solutions for power provision include various battery types such as standard alkaline batteries (AA, AAA, 9V), lithium-ion batteries (LiPo), and lithium iron phosphate batteries ($LiFePO_4$), as well as power sources like solar panels and direct power lines (wall outlets). Additionally, computer and laptop batteries, as well as power supply units (PSUs) housed within their chassis, are often considered.

It is important to note that any portable power solution typically offers less autonomy compared to on-site power sources. However, rechargeable batteries emerge as the most prevalent choice due to their versatility and ability to sustain operations in remote locations where periodic status checks by maintainers are feasible.

In similar ways, sophisticated technologies like drones or rovers would not be able to perform their activities without large batteries or always-connected power supplies [21]. Every automated solution, especially those designed to operate without human assistance, will require energy for easy assembly. This underscores the importance of exploring further approaches to address this issue. Resolving such a challenge will empower designers and engineers to fully leverage the current purposes aligned with the latest tech- nological innovations. Consequently, a more mature smart farming solutions market will emerge.

E. NETWORKING

The literature has shown different aspects to consider when choosing a network, one of these considerations is the scalability of the smart farming solution and the area that is going to be covered, this can be classified in large-scale architectures, that will cover extensive areas, and short range and small-scale applications, that are designed for compact and localized applications. On the large-scale side, there are protocols like LoRaWAN, that enable nodes to be positioned far from the gateway, but it will not transmit big amounts of data, perfectly fit for smart farming data. On the other hand, the short-range and small-scale solutions, WiFi emerges as a predominant choice due to its widespread availability and high data transfer rate. WiFi modules are familiar to researchers, making them accessible and facilitating wireless communication easily, but there are also protocols like Zigbee that enable low-cost low-power wireless networks.

Other architectures may need real-time data processing, for this matter, protocols are operating at higher layers, such as MQTT, which are suitable for applications demanding real-time data processing and communication.

Lastly, given the importance of energy efficiency in smart farming applications, particularly in remote and resource-constrained environments, prioritize protocols that contribute to reduced power consumption. LoRaWAN and Zigbee, with their low-power characteristics, are suitable choices for applications requiring efficient data transmission over extended periods while conserving energy.

F. DATA STORAGE

In smart farming environments, researchers prioritize data storage solutions that provide transparency, reliability, security, and decentralization [50]. This enables automated and optimized management of agricultural systems. By employing such solutions, researchers can ensure secure storage of agricultural data and efficient access, facilitating seamless communication and decision-making processes within the farming ecosystem. Additionally, decentralized data storage

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helps mitigate the risk of single points of failure and enhances data resilience, crucial for maintaining uninterrupted opera- tions in agricultural settings. Moreover, automated manage- ment systems leverage these storage solutions to streamline agricultural processes, optimizing resource allocation and enhancing overall productivity.

Both local and cloud solutions serve their purposes effectively, each catering to the specific needs of farmers. The choice between them ultimately hinges on the unique requirements of the farmer and their locality. As these prototypes continue to evolve, they are bound to transform into more robust devices. The selection criteria for these solutions will be shaped by various factors including the geographic location of farm crops and the specific needs of end-users. Local solutions tend to mature rapidly due to their close alignment with immediate needs, whereas cloud-synced options provide a more seamless guarantee of data integrity, confidentiality and availability.

G. DATA PROCESSING

The literature has shown three key methods to manage the data generated by the designed solutions, each suited to differ- ent scenarios and considerations [26], [33]. For smart farming solutions aiming at maximum efficiency and automation, the adoption of artificial intelligence (AI) is recommended with a focus on machine learning (ML) [33]. ML algorithms can analyze and interpret data autonomously, responding to the status of crops and dictating necessary parameters for plant care. This approach, exemplified by cloud-based ML algorithms analyzing drone-captured images, enables the system to make data-driven decisions, optimizing agricultural processes and reducing reliance on manual intervention. Such systems are particularly suitable for large-scale farming operations where automation can enhance efficiency [33].

In scenarios where environmental conditions are sta- ble and simpler data processing is preferred, the use of threshold-based approaches for setting predefined limits can be effective [26]. This method, highlighted in some studies, triggers specific actions based on predetermined thresholds. While it may lack the adaptability of AI-driven systems, this approach is straightforward and overall useful for small- scale architectures. Consider threshold-based data processing for applications where simplicity and stability are prioritized over complex automated systems [26].

For smart farming solutions that require direct human intervention and decision-making, especially in situations where human expertise is crucial, manual data processing methods should be considered [26]. This approach involves experts or domain specialists inspecting and making sense of raw data, identifying patterns or anomalies that may not be easily discernible through automated means. This hands-on approach allows for qualitative understanding, drawing on human expertise and contextual knowledge [26].

It’s important to note that the choice of data management method should also consider implementation costs, particu- larly in the context of low-cost smart farming architectures analyzed in the literature [26], [33]. AI-driven systems may require significant computational resources for train- ing models, while threshold-based approaches and manual data processing methods may offer more cost-effective alternatives. Additionally, the availability of existing data for AI modeling and the priority of developing web or mobile applications can influence the selection of data management methods [26], [33].

H. INFORMATION DELIVERY

The literature has shown key factors to consider when selecting the appropriate method for presenting information to users in the realm of smart farming. Different ways of presenting information in smart farming can provide usability features such as interactivity, personalization, ease of interpretation, and accessibility [37]. User experience varies depending on the type of data and the solution used, with screen size influencing usability. The availability of real-time information is critical for agile decision making in agriculture.

On the contrary, [12] suggests that different methods of presenting information in smart farming have different time and resource implications. For example, setting up a web system may require more upfront time and resources compared to a mobile application installed directly on devices. Updates in web systems are typically centralized, while mobile applications may require individual updates on each device, making the process more cumbersome. In addition, installation and update requirements are different for web systems, mobile applications, and desktop applica- tions. While web systems are accessible through compatible web browsers, mobile applications must be downloaded and installed on each device. Maintenance also varies, from managing servers and databases for web systems to updating applications in mobile stores.

From an operating system perspective, the development of a web application for crop recommendation in smart farming is important [38]. It affects the compatibility and accessibility of information presentation options, as certain features may vary. Developing specific applications for specific systems offers better performance and advanced functionalities but may entail platform limitations and additional costs. Con- versely, universal solutions such as web systems are more accessible, but may lack performance and functionality. The decision depends on factors such as performance, required functionality, accessibility, and development costs, with each approach having its pros and cons in terms of compatibility and accessibility.

Regarding implementation costs, [43] discusses the costs associated with developing, implementing, and maintaining smart agriculture solutions. It mentions the development of a customized web platform, which involves upfront costs for design, programming, testing, and ongoing maintenance costs such as software updates and technical support. Compared to simpler solutions such as cloud services or email, custom development may be more expensive initially, but offers more control and specific functionality. Other factors impacting costs include ongoing technical support and system scalability, with custom solutions potentially requiring more resources but offering greater customization flexibility and advanced functionality.

VI. REAL-WORLD APPLICATIONS

The application of smart farming technologies has proven to be effective in various agricultural contexts. A notable project implemented an IoT-based agricultural monitoring and automation system using low-cost sensor nodes to create a wireless sensor network (WSN) [10]. The farm faced challenges in efficiently managing irrigation and monitoring environmental conditions due to variability in soil moisture and climate, leading to inefficient water use and fluctuations in crop quality. The IoT system enabled real-time collection and transmission of critical data such as temperature and soil moisture to a cloud platform. As a result, decision- making became more precise, reducing water usage by 10% through irrigation automation and canceling unnecessary irrigation when rain was forecasted. This approach enhanced long-term sustainability by reducing reliance on manual and less accurate methods, increasing production efficiency and quality by 12%. In another case, an IoT-based telemetry and control system was implemented in a greenhouse [2]. This system optimized the environmental conditions necessary for plant growth by integrating GPRS sensors, a real- time visualization platform (ThingSpeak), and a mobile application (Blynk) for remote device control. Automation and real-time monitoring led to more efficient resource use, resulting in a 12% reduction in water consumption and a 3% reduction in energy consumption, while simultaneously improving crop production and quality by 9%. These outcomes promote more sustainable agricultural practices and demonstrate the effectiveness of smart technologies in agricultural management. Finally, a study investigated the use of a virtual soil moisture sensor based on deep learning in an olive grove in Pisa, Italy [9]. Through the deployment of sensor nodes and the use of LSTM algorithms, the system provided more accurate soil moisture estimation, optimizing irrigation and reducing water and pesticide consumption. The results indicated a significant improvement in the efficiency and sustainability of traditional farming practices, presenting a more advanced alternative for crop management.

VII. INTEGRATION AND SCALABILITY OF IoT TECHNOLOGIES IN AGRICULTURE

IoT technologies have been successfully integrated into
various crop sizes, showing their versatility. In small gardens, humidity and temperature sensors are used to adjust irrigation and optimize water use [81]. In medium-sized plantations, automated irrigation systems and monitoring platforms that integrate climatic data have significantly improved resource efficiency, including water and fertilizers [37]. Large farms employ sensor networks and drones to monitor and manage crop health precisely, enabling more efficient large-scale production [37].

The results and challenges of implementing IoT technolo- gies vary by crop size. Small crops have achieved notable irrigation optimization, but face challenges related to initial investment and maintenance [37]. Medium-sized crops see improved efficiency but struggle with integrating various technologies and training staff [37]. Large crops benefit from

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enhanced efficiency and cost reduction but face challenges with managing large data volumes and requiring robust infrastructure [37].

To maximize IoT technology efficiency, it is important to adapt solutions to local conditions and specific crop characteristics. This involves customizing irrigation and monitoring systems and designing flexible technological solutions that allow adjustments according to crop size and environmental conditions [81]. Additionally, IoT platforms and cloud-based monitoring systems have proven highly scalable, enabling initial deployment in small areas with gradual expansion as benefits are validated [36].

It is recommended to adopt a step-by-step implementation strategy, starting with basic solutions and expanding as experience is gained or specific crop size settings are defined. Customization and flexible design of technologies are key to their adaptation and scalability. It is also important to consider factors such as existing infrastructure, implementation costs, and the technical capacity of farmers.

VIII. STATISTICAL ANALYSIS OF PERFORMANCE AND EFFICIENCY OF DIFFERENT TECHNOLOGIES

The diverse architectures in smart farming systems present a significant challenge when attempting to perform a direct comparison of their performance and efficiency. Each system is composed of distinct components, ranging from varied power supply methods to different processors and communication protocols. This variation makes it difficult to draw generalized conclusions about which architecture performs best overall.

Many existing studies provide valuable insights but tend to focus on specific aspects of smart farming technologies, such as the implementation of a particular neural network or the efficiency of a certain communication protocol. For example, one study analyzes the role of energy-constrained sensors in a smart farming architecture, particularly how these sensors, like humidity sensors, need to report data frequently to inform irrigation systems. The study demonstrates that by employing a scheduling mechanism based on Deep Reinforcement Learning (DRL), the system can significantly prolong the lifetime of battery-powered sensors, more than doubling their life expectancy compared to non-adaptive methods. This finding underscores the potential of combining data analytics with DRL to enhance the sustainability and efficiency of IoT deployments in smart farming scenarios [72]. Another study focuses on the Firmware Update Over The Air (FUOTA) process for TinyML models within a LoRaWAN agricultural network. It highlights the feasibility and energy efficiency challenges of remotely updating firmware for smart devices used in agriculture. While the study shows that FUOTA is feasible, it also notes that updating large-size firmware over LoRaWAN can be energy-intensive and prone to interference when multiple devices are updated simultaneously. The research suggests future optimization of the FUOTA process to improve energy efficiency and explores the use of hybrid communication technologies, such as combining LoRaWAN for standard data transmission and LTE for firmware updates [82]. Additionally, another paper evaluates a Smart Agriculture Monitoring and Management System that utilizes IoT-enabled devices connected through a LoRaWAN network. The study finds the system effective in controlling crop growth parameters and emphasizes its power efficiency, with deep-sleep modes reducing power consumption by up to 83% for sensors and 86% for actuators compared to active modes. The system is also highlighted for its cost-effectiveness, scalability, and ease of maintenance, making it a promising candidate for widespread adoption in smart agriculture [28].

However, such studies often do not offer a comprehensive analysis of the entire system's performance in a real-world agricultural setting, leaving gaps in our understanding of how different architectures function as a whole.

Given the wide range of factors involved, comparing these technologies across the board is problematic. For instance, while some systems may excel in processing power, they might be less efficient in terms of energy consumption. Others might offer robust communication capabilities but fall short in data processing speed. These differences underline the complexity of evaluating smart farming architectures holistically.

In light of these challenges, future research could benefit from the development of standardized benchmarks and more holistic evaluation methods. Such approaches would provide a more robust foundation for comparing different smart farming architectures, allowing for more meaningful conclusions about their relative performance and efficiency.

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IX. EXPERIENCE, AND THE SOCIO-ECONOMIC IMPACT OF SMART FARMING TECHNOLOGIES ON FARMERS AND RURAL COMMUNITIES

Smart farming technologies, encompassing digital sensors, artificial intelligence (AI), and the Internet of Things (IoT), have significantly enhanced farm management and decision- making processes. These technologies provide real-time data and integrated digital solutions, thereby improving farmers' technical efficiency and knowledge. The implementation of these tools offers actionable knowledge and facilitates integrated, real-time decision-making, which is crucial for modern agricultural practices [23]. Additionally, the adoption of user-friendly interfaces, such as mobile and web appli- cations, enables farmers to interact with these technologies more effectively, ensuring improved monitoring and control of farming operations. Non-GUI interfaces, including speech, haptics, and gestures, are particularly beneficial in regions with literacy challenges, further enhancing the overall user experience [42], [88].

With 90% of U.S. farmers now using smartphones to manage their operations, the shift toward digital agriculture is undeniable [90]. These mobile apps have been instrumental in improving decision-making processes, with some estimates suggesting a productivity increase of up to 30% through better data accessibility and resource management [91]. This demonstrates the crucial role that accessible technology plays in modern farming, particularly when considering the socio- economic impact.

The socio-economic impact of smart farming technologies is profound, contributing to increased agricultural efficiency, profitability, and sustainability. For instance, precision agri- culture technologies, such as GPS-guided equipment, can reduce costs by up to 25% while simultaneously increasing crop yields by 5% [90]. This optimization of resource utilization, along with reduced labor requirements, has led to significant improvements in farm management practices. Consequently, farms have experienced enhanced productiv- ity, resilience, and environmental performance [23]. More- over, digital agriculture provides broader socio-economic benefits, such as improved financial management, market competitiveness, and enhanced access to finance, advisory services, insurance, and markets for smallholder farmers. This leads to greater economic stability and improved livelihoods for small-scale producers [42]. Furthermore, the integration of sustainable farming practices through digital and geospatial technologies supports climate change mitigation and biodiversity improvements, thereby contribut- ing to long-term environmental sustainability and societal benefits [23], [68].

Specific technologies have also led to notable increases in production. For example, the use of smart irrigation systems, which are estimated to reach a market size of $1.35 billion by 2025, can reduce water usage by up to 40% while maintaining or even increasing crop yields [90]. Similarly, AI-powered crop monitoring systems have been shown to detect plant diseases with up to 98% accuracy, preventing losses and ensuring higher productivity [90]. These innovations not only support sustainability but also ensure that farms remain competitive in a rapidly evolving agricultural landscape.

However, the adoption of smart farming technologies faces several challenges, including resistance from older farmers, a gap between farmers and technology providers, and the high costs associated with new technologies. Addressing these barriers is crucial for the successful implementation and long-term sustainability of smart farming systems. Overcoming these challenges will ensure that the benefits of digital agriculture can be fully realized, leading to enhanced food security, sustainability, and economic development in rural communities [35], [68].

X. CONCLUSION

From simple connectivity to integrating cutting-edge technology like artificial intelligence and real-time analytics, the Internet of Things (IoT) has experienced substantial development. Numerous industries, including manufacturing, logistics, healthcare, and agriculture, have been significantly impacted by this trend. IoT's disruptive potential resides in its power to completely change how people interact with the physical world, facilitating quicker decision-making, increased operational effectiveness Cost reduction ,and new business opportunities across diverse applications such as smart cities, eHealth, Industry 4.0, and smart homes.

Nevertheless, despite its potential, there are obstacles to the broad use of IoT in smart farming, chief among them being farmers' ignorance. The implementation of contemporary agricultural technologies is hampered by persistent issues, such as a lack of financial resources, technology, and education. Undefined standards, coverage and connectivity problems, high costs, reluctance to adopt new technologies, and a lack of skilled labour are some of the difficulties.

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Adoption is further hampered by the absence of guidance models for IoT-based monitoring systems and the low level of awareness among rural farmers.

We analysed new trends and determined best practices in the field of smart agriculture after gathering and classifying pertinent papers. We were able to clarify the development of smart farming solutions through this analysis, pointing out technological breakthroughs, difficulties, and suggestions for choosing tools and technologies.

According to our research, implementing smart farming requires intricate interactions between a number of different components, such as power supplies, gateways, sensor kinds, data storage, data processing, and information transportation. In order to build a complete ecosystem that enables farmers to make wise decisions and maximise their agricultural practices, each of these components is crucial. This study highlights the significance of IoT as a catalyst for change in the agricultural industry and offers a thorough understanding of new technologies in the field of smart agriculture. By providing insightful advice to individuals interested in putting smart farming solutions into practice and optimising their influence on the effectiveness, sustainability, and productivity of agricultural operations, we hope to further the field's research.

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