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Research Article

Smart Farming Platform Using IoT and UAVs

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ABSTRACT

With the advancement of communication technology, many innovative applications have developed in agriculture as a result of the integration of the Internet of Things (IoT) with unmanned aerial vehicles (UAVs), leading to the modernization of agriculture. This study seeks to propose an effective and low-cost platform for comprehensive monitoring of environmental parameters using IoT and drones.The preparation of this paper was based on a platform that was tested in a realistic environment on a farm near the city of Al-Median in Tunisia, where the platform was built to suit the realistic environment of a farm in Baghdad, through the use of sensors above and below the ground, which meets the experimental work and standards for automated and real-time monitoring. For environmental standards, the unified theory of acceptance and use of technology model was used, which is a model based on four basic elements: 1) expected performance, 2) expected effort, 3) social impact, and 4) facilitating conditions for obtaining results. The unique integration of IoT sensors with drones has shown impressive experimental results, indicating the possibility of performing both automatic and manual actions by humans. These smart moves contribute significantly to promoting precision agriculture, leading to a significant increase in agricultural production and conservation of natural resources.

Keywords: Internet of Things; unmanned aerial vehicles (UAVs); smart agriculture; environmental parameters

1. INTRODUCTION

The world's population is on an upward trajectory. As per the projections of the Food and Agriculture Organization, it is estimated to reach 9.73 billion by 2050 and a staggering 11.2 billion by 2100, marking a substantial increase of more than 25% [1]. Accompanying this population boom is the pressing need to quadruple food production by 2050 to adequately cater to this expanding populace [2]. An example of this demand is the expected increase in grain production from the current estimate of 2.1 billion tons to nearly 3 billion tons [3]. This impending challenge underscores the critical imperative to boost agricultural production to meet global food requirements [4].

However, the availability of arable land faces constant threats from factors such as population density, urbanization, and changing land and climate patterns [5]. For instance, the total arable land for food production that stood at 19.5 million square miles (or 39.47% of the planet's land area) in 1991 dwindled to approximately 18.6 million square miles (or 37.73% of the planet's land area) by 2013 [6]. Consequently, the gap between food supply and demand continues to widen, raising significant concerns. In response to this challenge, experts in the field emphasize the need to employ scientific techniques and technology in agriculture to enhance farm management, ultimately boosting crop production and preserving natural resources [7, 8], [9, 10]. Figure 1 illustrates how the Fourth Industrial Revolution (4IR) has brought scientists, engineers, and IT professionals together to leverage cutting-edge technology for the betterment of life on Earth [11, 12].

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One of the key pillars within the 4IR is the Internet of Things (IoT), often referred to as the driving force behind the 4IR, as it effectively connects billions of devices and sensors to provide real-time data. Predictions indicate that by 2025, more than 100 billion devices will be interconnected [13, 14].

IoT technology's proliferation is inevitable as it continues to permeate various sectors and industries, including manufacturing, health, communications, energy, and agriculture [15]. In agriculture, IoT technology has been harnessed to manage data gathered from diverse farming environments, providing farmers with real-time insights into their fields [16]. Simultaneously, scholars have expressed growing interest in the integration of IoT and unmanned aerial vehicles (UAVs) for several compelling reasons. UAVs are known for their reliability, adaptability, portability, line-of-sight connectivity, efficiency, versatility, rapid deployment, and cost-effectiveness. They can take various forms, including drones, high-altitude platforms, low-altitude platforms, and tethered platforms [17, 18], and have gained significant attention from both industry and academia due to their versatility and wide range of applications, such as telecommunications, disaster relief monitoring, enabling smart cities, atmospheric studies, service delivery, surveillance, high-resolution photography, and military applications [19, 20] (Figure 1).

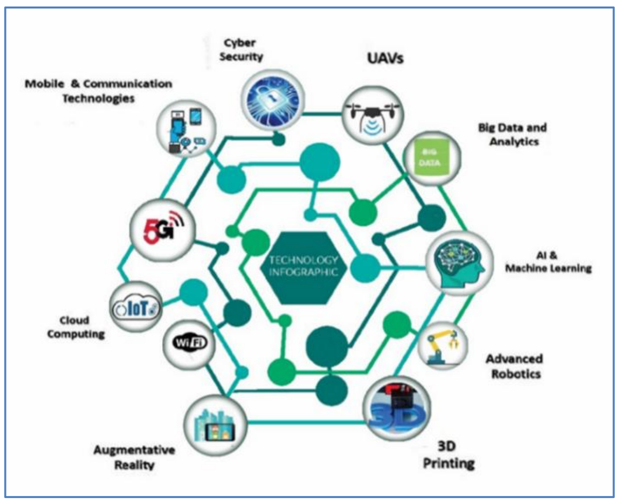

Fig. 1. IoT and UAV, among other technological foundations.

Goldman Sachs' prediction indicates that the agriculture industry will lead the world in utilizing drones within the next five years [21], signifying the rapid growth of UAV usage in agriculture. UAVs are aiding farmers in monitoring their fields, making informed decisions, and promoting crop growth through the collection of field data in a more convenient, rapid, and cost-effective manner when compared with traditional methods [22]. Through cloud-based systems, farmers and stakeholders can remotely access the data acquired by UAVs via applications on their smart devices, enabling them to estimate crop production and make informed choices regarding pesticide and fertilizer use, seed planting, and more. This approach encompasses a wide array of agricultural parameters, including environmental conditions, growth status, soil conditions, irrigation water management, pest control, fertilizer utilization, weed management, and greenhouse production environment, with the ultimate goal of enhancing crop yields, reducing costs, and optimizing resource inputs (Figure 2) [23]

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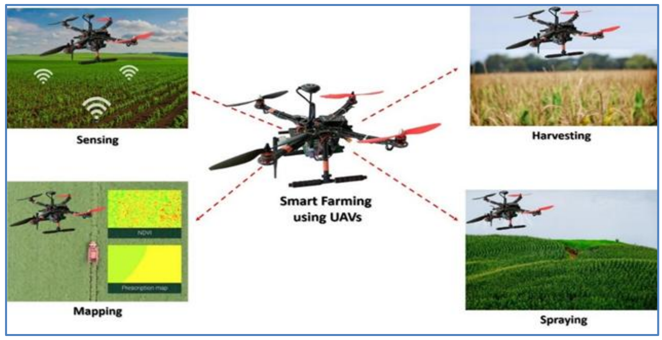

Fig. 2. Different types of agricultural UAVs.

The synergy of IoT and UAV technologies has paved the way for the realization of sustainable smart farming, automating data collection and analysis to enhance productivity and farm management practices [24].

1.1. Motivation and Contribution

The motivation for preparing this comprehensive review issues from the fact that IoT and UAV are the two key enabling technologies in smart farming. Undoubtedly, IoT and UAV will be the leaders of the fourth revolution in smart agriculture for the upcoming years. The bibliographic analysis of the review involved a keyword-based search for conference and/or journal articles. The scientific research databases of IEEE Xplore and ScienceDirect, as well as the scientific web search engine of Google Scholar, were selected to perform this review. The main contributions of this research are summarized as follows:

In this work, we combine two key enabling technologies in a single paper review, as these technologies play (now and in the future) a pivotal role in the agricultural industry. The agricultural industry, and in general the agricultural economy, is expected to be undoubtedly transformed by the adoption of these two enabling technologies on a large-scale cultivation basis. Also, we outline enabling techniques incorporated with IoT technology, describe the main application of these techniques in agriculture, and point out the benefits derived by their utilization. Moreover, we perform a detailed analysis of applications that use UAV technology in smart farming. This approach is applied not only from the technological point of view, which is actually significant yet of interest and usefulness only to workers in the field, but also from the agricultural point of view as well, noting all the key aspects in this research field. To the best of the authors' knowledge, this work is the first to use this approach in a review article. Finally, the unified theory of acceptance and use of technology (UTAUT) project framework, as a use case of combined state-of-the-art technologies, is briefly described. The use case is included in this review to exploit the importance of the incorporation of various emerging technologies, such as IoT technology and UAVs, to promote rational use in agriculture.

2. RELATED WORKS

Agriculture is crucial to economic growth, accounting for 4% of the global GDP. In some least developed countries, it can account for more than 25% of the GDP. Despite the small percentage that agriculture represents in the global economy, it employs about 30% of the world's labor [5]. In rural areas, farming families are gradually losing the next generation of farmers, overwhelmed by higher costs of cultivation, low per capita productivity, inadequate soil maintenance, and migrations to a non-farming or higher remunerative occupation. Presently, the world is on the verge of a digital revolution. Thus, now is the appropriate time to connect the agricultural field with wireless technology to introduce and accommodate digital connectivity with farmers.

Regrettably, not all parts of the Earth's surface are suitable for agriculture due to various restrictions, such as soil quality, topography, temperature, and climate. Most relevant cultivable areas are also not homogeneous [6] (Figure 3). Recently, the total agricultural land used for food production has declined [7]

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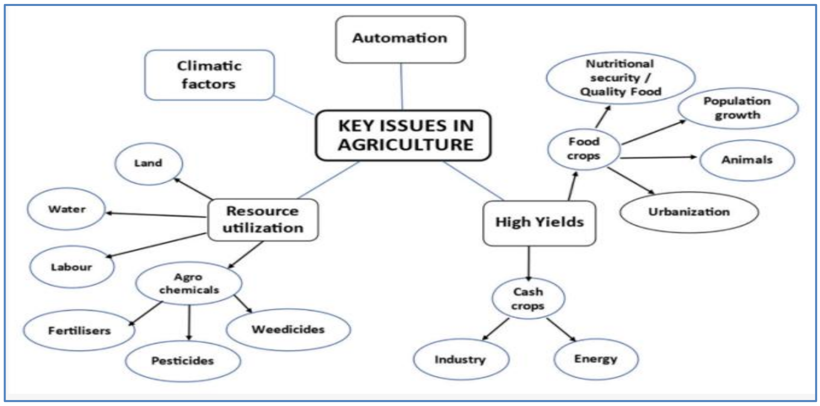

Fig. 3. Key issues of technology in the agriculture industry.

The above findings highlight the need for technology-driven solutions in agriculture to overcome challenges and achieve more efficient and sustainable food production, with the following key points:

- *Site-specific analysis:* Different crops and even sections within a single crop may require specific management approaches for optimal yields. This situation necessitates site-specific analyses, and new technology-based methods are required to address these variations.

- *Remote monitoring:* Traditional farming practices often involve frequent physical visits to fields to assess crop conditions. Modern sensor and communication technologies allow farmers to remotely monitor their fields with high precision. Wireless sensors provide real-time data, enabling early issue detection and the use of smart tools throughout the crop's life cycle.

- *Precision farming:* The timely use of sensors and data-driven insights makes farming operations more efficient and cost-effective. Autonomous machinery, robotic weeders, and drones equipped with sensors collect data at regular intervals, enhancing precision in farming practices.

- *Sustainability:* Agriculture's vast scale places significant demands on technology solutions for sustainability. Wireless sensor technology, coupled with data-driven insights, allows farmers to understand their crops' specific needs and take remote actions, reducing the ecological impact of farming.

Incorporating these technological advancements into agriculture can lead to more sustainable, efficient, and environmentally friendly farming practices.

This section provides a state-of-the-art overview of IoT and UAV technologies in smart farming, focusing on connectivity requirements, communication methods, and network features. A low-cost LoRa-based IoT platform called LoRaFarm is introduced, designed to enhance flexible farm management. It was tested on a world farms, collecting environmental data for crop growth. In addition, a hierarchical smart farming system, combining wireless sensor networks (WSNs) and UAVs, was created for crop monitoring [25, 26].
Key components of this research include designing UAV trajectories for efficient data collection and developing data processing algorithms at the network level. Experiments at a Romanian research facility demonstrated the effectiveness of the cooperative UAV-WSN-IoT approach in ecological and smart farming. A smart agricultural management system was developed to increase crop yields, utilizing sensors to collect growth-related data, processed through the ThingSpeak IoT cloud platform and the Firebase Database [27, 28].

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Authors in [29] utilized a genetic algorithm to develop a system for assessing crop water requirements based on rainfall predictions. The system stores extensive meteorological and soil moisture data in cloud servers. A mobile application is used to monitor and control water spraying based on data collected by UAVs, which were then analyzed by GA. Soil moisture levels trigger the sensor-based system, and quadrotor UAVs irrigate plants when moisture levels exceed a predefined threshold [29].

[30] developed a system to monitor agricultural pests and diseases by using IoT and UAVs, applied in the Yangtze River Zone of China. The system employs low-altitude remote sensing and aerial photography for pest and disease monitoring, with the potential for climate change research to identify preventive measures. [31] proposed the use of a UAV network and narrowband IoT (NB-IoT) to collect subterranean soil data in potato crops. The study highlights challenges related to link quality based on UAV height and route loss, as well as variations in sensor battery life above and below ground. Future work aims to improve accuracy and performance using LoRa technology and suitable route loss models. In [21, 24], the authors investigated various propagation path loss models, both deterministic and empirical, suggesting model selection based on coverage area, terrain, and quality of service (QoS) considerations.

In [32], the authors introduced a heterogeneous IoT sensor node system to measure acoustic, rain, wind, light, temperature, and pH levels in cornfields. The system aims to enhance production in large fields by using drones to collect data and transfer it to a gateway. Simulation results, tracked with the IoT application Grafana, demonstrate increased soil efficiency, precise crop development tracking, reduced workload, lower disease and pest risks, optimized irrigation, and improved product quality at a reasonable cost. Future work could involve gathering more meteorological and geographic data to create a comprehensive model of smart farming [32] .

3. SMART FARMING

The twentieth century ushered in the era called Agriculture 3.0 with the rise of computation and electronics. Robotics, programmed machinery, and other technologies resolved the issues of the 2.0 era. Precision irrigation, reduced chemical use, and efficient pest control became the norm.

Today, we are in Agriculture 4.0, an era characterized by advanced technologies such as IoT, big data analysis, artificial intelligence (AI), cloud computing, and remote sensing. These innovations have optimized production efficiency while conserving resources and minimizing environmental impact. Smart farming relies on real-time data and AI to make informed decisions for sustainable agriculture. Smart farming leverages advanced technology to enable remote plant monitoring, automation, and precision agriculture. It enhances processes such as harvesting and crop yield by using automated sensors and machinery, thereby increasing workforce efficiency and launching a technological revolution in agriculture [17]. This modern technique employs information and communication technologies (ICTs) [16], including IoT, GPS, sensors, robotics, drones, and data analytics, to address farmers' needs and enhance decision-making accuracy and timeliness while improving crop productivity.

Smart farming is endorsed by multilateral organizations and developing countries as a means to boost agricultural output [18]. Sensors provide precise and early monitoring of crops, offering efficiency and profitability throughout the entire farming process. They address various crop production challenges by monitoring soil conditions, climate, and moisture to enhance spatial management, increase crop yields, and reduce the use of fertilizers and pesticides. Smart agriculture employs IoT technologies for real-time benefits in irrigation, plant protection, quality improvement, fertilization, and disease prediction. It collects real-time data on crops, assesses soil and crop conditions, enables remote monitoring, and enhances livestock and agricultural production [20, 22].

Smart agriculture represents the modernization and smart advancement of precision agriculture, providing remote management and real-time solutions for various farm activities.

4. INTERNET OF THINGS

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The IoT is a new technology that allows devices to connect remotely to achieve smart farming [21]. The IoT has begun to influence a vast range of industries, from health, trade, communications, energy, and agriculture, to enhance efficiency and performance across all markets [22, 23], [24]. Current applications provide information on the IoT's effects and its practices that are yet to be observed. However, by considering the advancement of technologies, one can envisage that IoT technologies perform a crucial role in numerous farming activities, such as the utilization of communication infrastructure, data acquisition, smart objects, sensors, mobile devices, cloud-based intelligent information, decision-making, and the automation of agricultural operations (**Figure 4**).

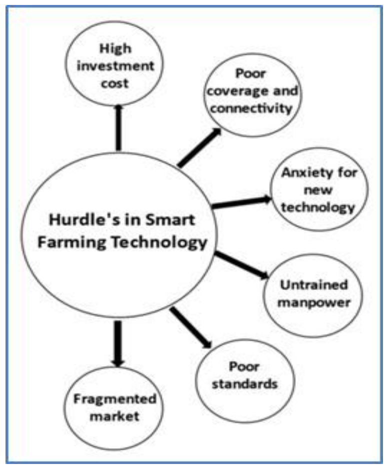

Fig. 4. Barriers in the implementation of smart agriculture technology.

Recently, the development of IoT technologies has played a major role throughout the farming sector, particularly through its communication infrastructure. This has included connecting smart objects, remote data acquisition, using vehicles and sensors through mobile devices and the Internet, cloud-based intelligent analysis, interfacing, decision formation, and the automation of agricultural operations. These proficiencies have revolutionized the agriculture industry in terms of resource optimization, controlling climate effects, and improving crop yields. have proposed different methods, architectures, and equipment to monitor and convey crop information at different growth stages based on several crop and field types. Many manufacturers provide communication devices, multiple sensors, robots, heavy machinery, and drones to collect and then distribute data. Food and agriculture organizations, along with other government organizations, develop guidelines and policies for regulating the use of technologies to preserve food and environment safety [27, 28, 33].

4. TECHNOLOGIES USED IN SMART FARMING

4.1. Global Positioning System

A global positioning system (GPS) accurately records latitude, longitude, and elevation information [34]. GPS satellites transmit signals and permit GPS receivers to compute their location in real time and provide continuous positions while moving. The exact location information offers farmers the opportunity to discover the precise position of field data, such as pest occurrence, type of soil, weeds, and other barriers. The system facilitates the recognition of various field locations to then apply the necessary inputs (seed, fertilizer, herbicide, pesticide, and water) to a particular field [31].

4.2. Sensor Technologies

Various techniques such as photoelectricity, electromagnetics, conductivity, and ultrasound are used to estimate soil properties, nutrient levels, and environmental conditions. Remote sensing data helps differentiate crop types, identify pests and weeds, assess soil and plant stress, and monitor drought. Monitoring plant health involves factors such as soil

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moisture, nutrient availability, and light exposure, with sensors used to detect these parameters. Wireless sensors are crucial for collecting crop data and can be integrated with advanced agricultural tools and machinery as needed. These sensors are valued for their reliability, memory, portability, durability, coverage, and computational efficiency in agricultural applications. [5, 32].

4.3. Variable-rate Technology and Grid Soil Sampling

Variable-rate technologies in agriculture use maps created from grid soil sampling to determine the precise application rates of inputs, such as fertilizers [16, 31], at different locations within a field. These maps are loaded into a variable-rate applicator, and a computer with a GPS receiver directs the application changes based on the map data. [35]. This technology, including grid soil sampling, helps manage soil fertility, assess nutrient distribution, and improve nutrient management practices for better precision agriculture by customizing fertilizer and manure applications for each field's specific needs [30].

4.4. Geographic Information System

A geographic information system (GIS) comprises hardware and software designed to provide compilation, storage, retrieval, attribute analysis, and location data to generate maps and analyze characters and geography for statistics and spatial methods [35]. The GIS database provides information on field soil types, nutrient status, topography, irrigation, surface and subsurface drainage, quantity of chemical applications, and crop production, and also establishes the relationship between elements that affect a crop on a particular farming field [36]. Apart from data storage and display, the GIS is used to assess present an alternative management approach by compounding and altering data layers for decision-making.

4.5. Crop Management Satellite Images

These images are used to monitor soil conditions, crop performance, and factors such as seeds, fertilizers, and pesticides that impact yield and efficiency. These images provide near-real-time data at a regional scale and are analyzed using vegetation indices such as NDVI to assess vegetation health and crop production. This approach allows for early crop yield estimation before harvest and supports automated farm operations, including yield analysis, weather prediction, field mapping, and soil nutrient tracking [30].

4.6. Soil and plant sensors

Sensor technology, a significant constituent of precision agriculture, provides soil property information, fertility, and water status. Hence, new sensors have been developed based on desirable features and established apart from currently available sensors [37]. Soil sensors and plant wearables monitor real-time physical and chemical signals in soil, such as moisture, pH, temperature, and pollutants, and provide information to optimize crop growth conditions, fight against biotic and abiotic stresses, and increase crop yields. Soil apparent electrical conductivity (ECa) sensors collect information continuously on the field surface because ECa is sensitive to changes in soil texture and salinity. Soil insects/pests are detected using optoelectronic, acoustic, impedance sensors, and nanostructured biosensors [38].

4.7. Rate Controllers

Rate controllers are designed to control the delivery rate of inputs by monitoring the speed of vehicles across the field. altering the flow rate of material on a real-time basis at the target rate. Rate controllers are commonly used as stand-alone systems [39].

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4.10. Software

The software has multiple tasks, such as mapping, display controller interfacing, data processing, analysis, and interpretation. Most commonly, software is used to generate the maps for soil properties and nutrient status, yield maps, variable rate applications maps for inputs, and overlaying different kinds of maps with advanced geostatistical features [43].

5. UNMANNED AERIAL VEHICLES

UAVs, commonly known as drones, are a rapidly evolving and self-contained technology that incorporates a blend of various other technological components, including robotics, on-board computing, AI [21], ICT, the IoT, and advanced battery technology. UAVs are capable of capturing high-resolution imagery using hyperspectral, multispectral, and RGB cameras. In the field of precision agriculture, UAVs play a significant role in two primary phases.

Monitoring Phase: This phase involves soil and crop mapping and sampling [22], yield forecasting [23], detection of weeds [24], identification of pests and diseases [25], and assessment of soil and crop stress [26, 27].
Action Phase: This phase involves sowing seeds [33] and application of herbicides [28], pesticides [29], and fertilizers [30].

The two main types of UAVs are fixed-wing UAVs and rotary-wing UAVs, as shown in Figure 5.

- **Fixed-wing UAVs** are more akin to airplanes and are particularly suitable for covering large agricultural areas due to their extended range, high speed, altitude capabilities, and crash tolerance.
- **Rotary-wing UAVs** have further classifications, including helicopters and multirotor types. Multirotor UAVs are often named according to the number of rotors they possess, such as quadcopters (four rotors) [31, 32], hex copters (six rotors) [5], and octocopters (eight rotors) [30]. These UAVs operate in a manner similar to helicopters and offer advantages such as ease of setup and operation, low-altitude flight, precise location operation, no need for wind planning, and full autonomy for daily agricultural tasks.

Despite their advantages, UAVs also have limitations, such as the following technical limitations:

1. **Low battery time and efficiency**: UAVs often have limited flight time due to battery constraints.
2. **Payload**: The amount of weight a UAV can carry is restricted.
3. **Communication distance**: The range at which UAVs can communicate is limited.
4. **Short flight time:** The flight time can be relatively short.

Fixed-wing UAVs can communicate up to 100 kilometers and have an average flight time of about 5 hours [44]. Researchers are actively working on improving battery efficiency by developing hybrid battery technology and battery management and optimization techniques to address these limitations [45][46].

Fig. 5. Two main types of UAVs.

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6. COMMUNICATION TECHNOLOGIES

In smart agriculture, communication technologies are essential for transmitting and analyzing data. Different technologies suit various applications, with Zigbee being ideal for greenhouse monitoring and NB-IoT and LoRa being suitable for field precision agriculture. When choosing a technology, considerations include licensed versus unlicensed spectrum options, bandwidth, and security [45]. A survey suggests that ZigBee, Wi-Fi, and cellular technologies are more popular among researchers for agriculture applications. About 45% of Zigbee, 25% of Wi-Fi, and 20% of cellular or multihopping technologies are utilized by researchers for agriculture-related experiments [47]. NB-IoT and long-term evolution machine are relatively new low-power wide-area (LPWA) technologies and could capture more attention as the 3rd Generation Partnership Project, the standard group specifying the fifth-generation mobile network (5G) and other wireless networking standards, has affirmed that these technologies will be a part of 5G and will be the only LPWA-supported 5G technology [48].

7. ROLE OF IOT IN ADVANCED FARMING PRACTICES

Adopting new sensor and IoT-based technologies has significantly enhanced crop yields compared with traditional agricultural methods. These technologies are instrumental in controlled environments, enhancing the quality and quantity of produce.

7.1 Greenhouse Farming and Protected Cultivation

IoT-based automation has improved rose plant productivity in greenhouses by closely monitoring parameters such as humidity, CO2 levels, UV light intensity, pH, water nutrient solutions, temperature, and pesticide levels.

7.2 Hydroponics

Hydroponics, a form of soilless cultivation, involves growing plants without soil, primarily in greenhouses. IoT-based hydroponic systems allow for real-time monitoring and control of nutrient levels and other parameters critical for plant growth. The deep flow technique of hydroponics involves placing plant roots in deep water layers with continuous nutrient solution circulation. Raspberry Pi integrated with sensors is used for real-time data processing and monitoring to ensure proper water circulation.

7.3 Vertical Farming

Vertical farming is a sustainable solution that minimizes resource consumption and maximizes production by growing plants in precisely controlled environments. IoT plays a role in monitoring critical parameters such as carbon dioxide levels using nondispersive infrared CO2.

7.4 Phenotyping

Phenotyping is an emerging technique that links plant genomics, ecophysiology, and agronomy to analyze various crop behaviors, including pathogen resistance and yield quality and quantity. IoT-based phenotyping aims to observe crop traits and provide support for crop breeding and digital agriculture. Trait analysis algorithms and modeling help understand the relationships between genotypes, phenotypes, and growing conditions, aiding crop improvement [49, 50], [51]. These technologies represent a significant advancement in modern agriculture, enhancing both productivity and sustainability.

8. ROLE OF THE ENGINEER IN SMART FARMING

Engineers play a crucial role in addressing challenges associated with IoT-based agriculture and smart farming. They utilize innovative technologies and methods, drawing knowledge from various areas like agricultural mechanization,

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mechatronics, instrumentation, control systems, and artificial intelligence [52, 53]. Precision agriculture is greatly enhanced by big data, satellite, and aerial imagery, leading to improved production efficiency while ensuring environmental protection. Engineers act as system integrators, bringing technical expertise and business acumen to both public and private sectors [54, 55].

8.1. Purpose

Purpose is based on the user's final requirement and influences the monitoring of crops during the growth period. Sensors provide the IoT solutions to their problems. For example, the end user is a corn farmer, faced by problems mainly concerning water usage and ensuring that a crop receives adequate water. Therefore, water level and moisture monitoring sensors are accommodated to prevent water wastage.

8.2. Technology

Distance plays an important role in technology selection because the sensors collect and send data to the server; hence, similar technology cannot be used for varying distances. For example, radio frequency identification or near-field communication and LPWA network technologies could send data over a distance of hundreds or even thousands of meters.

8.3. Power Requirements

Most IoT solutions are spread across a large farm, so developing low-power applications is better. However, more data transmission requires high data costs and power consumption; hence, designers need to consider developing cost-effective IoT solutions for farmers. Usually, engineers save costs with customized IoT-based farming solutions and develop apps for sending data less frequently.

8.4. Data Frequency

The end user's necessities are critical in deciding the number of sensors and data packets. Sometimes, a farmer does not require information frequently, but developers design an IoT application to function on a continual and real-time basis, with very high data frequency.

8.5. Placement of Sensors

Sensors are placed in such a way that they provide optimal performance, even if the farm has all the essential sensors with proper placement.

9. APPLICATIONS OF IOT IN AGRICULTURE

In the smart era of agriculture, almost all agriculture processes are driven by data acquired by continuous monitoring of on-site IoT devices. Smart agriculture applications that can only be performed by utilizing IoT are geospatial and temporal mapping and sampling [56], smart drip and sprinkler irrigation, pest and pathogen monitoring and controlling, yield assessment, precision fertilization, and environment maintenance. These applications are briefly discussed below.

9.1. Geospatial and Temporal Mapping and Sampling The simple and crucial application of precision agriculture can be used for crop field assessment and mapping. Applications that depend on geospatial and temporal sampling are weed management systems, water stress assessments, and vegetation indexes. Geospatial and temporal sampling can be used for spatial variability assessment using GIS [57]. Geospatial can be performed by using remote sensing, aerial surveys using planes, and remote imagery using UAV. Initially, it was expensive and not as efficient as it is today. With satellite

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remote sensing and cloud distortion, UAV has become cost-effective and more efficient and could be adopted as the first step for precision farming, even by farmers in developing countries such as Pakistan.

9.2. Smart Irrigation

The world has been facing the challenge of water scarcity. Pakistan is one country that is becoming water scarce, initially being a water-stressed country [58]. With the use of IoT and smart systems, weather-adaptive smart irrigation systems can be implemented and reduce the usage of precious resource water [59]. Smart irrigation is designed to irrigate only if necessary, depending on the crop and soil stress level. UAV is a great tool to deal with the variability factor of water stress; sprinkler irrigation can be performed using UAV for precise irrigation on the spot [60].

9.3 Pest and Weed Management System

Pest, weeds, and pathogens can affect crops harshly and may reduce productivity by up to 30% only by weeds [61]. However, pesticides and herbicides also reduce the profit and degrade the product quality, which is a major concern for consumers. IoT and smart systems can assess the disease, pest, and weed in crops in the early stages and can inform the farmer. IoT also helps eradicate pests and pathogens by precise targeting with pesticides and herbicides. Smart vehicles can also be used for this purpose [62].

9.4. Yield Assessment

Yield assessment is the most essential part of smart agriculture. For any type of assessment, data acquisition is the first step. Precise and continuous monitoring for the biotic and abiotic factors is only possible through IoT, WSNs, and UAV imagery. The acquired data can be utilized for the early prediction of disease [63], crop prediction [64], and harvest planning [65]. Through these applications, farmers can reduce their labor cost and operation cost, perform error-free assessment for diseases and pests, estimate the revenue and profit, and schedule and plan a more suitable harvesting period that results in less input cost and more profitability in the long run.

9.5. Precision Fertilization

Precision fertilization is another important application of IoT for agriculture, saving money and the environment at the same time. If plants require more nutrients than they were provided, then productivity and growth will decline. Another aspect is variability, which can only be handled through precision monitoring and mapping of land and crops. Smart IoT-based agriculture systems provide an optimal estimation of nutrient requirements [65] and reduce the labor cost and input costs.

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10. CHALLENGES AND SOLUTIONS OF USING IOT DEVICES IN SMART AGRICULTURE

The most significant limitation of using IoT devices is battery life. When using UAVs in agriculture, flight time is another issue along with the battery life. An in-depth study identified that this issue is an open area that requires various solutions [66]. Many researchers have worked to reduce these hurdles and proposed and tested solutions. Ultra-lightweight WPT systems were proposed to enhance UAVs' flight time [6]. The system is flexible enough to handle air-gap geometrical changes and can charge UAVs in midair, extending the flight time to around 7 minutes. The system can charge drones wirelessly with 10 W. In another work [67], a wireless charging system for UAVs was developed using capacitive power transfer technology. This system can charge UAVs on wide charging areas. Its emitting side comprises a circuit, transformer, and inductors. The receiving side comprises all the small devices using semiconductor elements for a DC-DC converter and charge controlling IC. Their prototype system works on around 12 W and provides more than 50% efficiency. While considering the magnetic resonant coupling technique due to its efficiency and capability of high-power transfer, [68] proposed and developed a wireless charging system for UAVs used in agriculture fields. In their experiments, they achieved maximum transfer power and efficiency by using FSC coil with 150 coil turns in the transmitter circuit and the MTC comprising 60 coil turns in the receiver UAVs.

Another major hurdle of using UAVs in smart agriculture is path loss while communicating wirelessly due to the surrounding environment. An accurate path loss model is essential for smart agriculture applications to ensure wireless data communication without unnecessary packet loss among each component of the system. [69] proposed and tested two improved models. Their simulation results show that the hybrid exponential and polynomial and particle swarm optimization models noticeably improved the coefficient of determination () of the regression line, with the mean absolute error of 1.6 and 2.7 dBm for both algorithms. The wireless underground sensor network (WUSN) faces the same path loss issues, and [70] proposed and developed a system based on an accurate prediction of the complex dielectric constant to handle the path loss for precision agriculture known as WUSN-PLM. WUSN-PLM outperforms the existing path loss models in different communication types and provides 87.13% precision and 85% balanced accuracy on cheap sensors.

11. MATERIALS AND METHODS

The described smart farming platform incorporates under- and aboveground sensors, along with a drone for monitoring. Figure 6 shows the platform, which consists of two segments: the space segment and the ground segment.

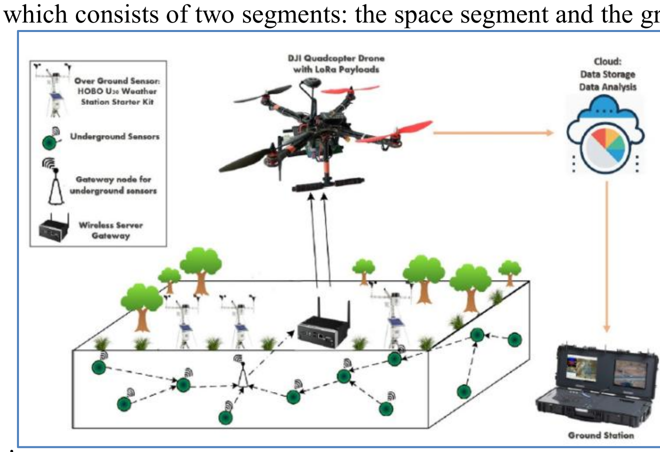

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Fig. 6. Overview of the agricultural IoT platform.

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Space segment: This segment includes a drone equipped with a camera and a LoRa module. The drone collects data from wireless server gateways and transmits it to the cloud for analysis.
Ground segment: This segment has three components:

- A ground control station controlled by the end user.
- An underground sensor gateway node for collecting data from soil moisture sensors.
- The HOBO U30 Weather Station Starter Kit, which includes aboveground sensors for measuring temperature/humidity, rain, and solar radiation.

The platform architecture contains five layers.

11.1. Sensor Node Layer

This layer includes the underground sensors for measuring soil moisture and aboveground sensors shown in Figure 7, which measure various environmental parameters such as temperature, humidity, rainfall, and solar radiation. These sensors provide comprehensive data for decision-making in agriculture.

Fig. 7. HOBO U30 Weather Station Starter Kit in Medicine, Tunisia.

11.2. Wireless Server Gateway

This layer collects data from sensor nodes and uses a LoRa module for aggregation and transmission. LoRa is a long-range, low-power network technology that allows data to be sent over long distances with low energy consumption.

11.3. Drone–LoRa Layer

This layer serves as the bridge between the wireless server gateway and the cloud, utilizing LoRa technology for data transmission. In remote areas such as farms where network infrastructure may be lacking or expensive to install, a drone is employed as a mobile gateway to periodically collect data from various sensors scattered across the farm. The drone offers mobility and flexibility, enabling access to remote and challenging locations, effectively acting as a flying LoRa gateway. The drone shown in Figure 8 is a versatile device equipped with multiple wireless interfaces for communication between IoT devices and the cloud. The system utilizes Dragino LG02, an open-source dual-channel LoRa gateway that

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can connect the LoRa wireless network to an IP network via various means such as Wi-Fi, Ethernet, 3G, or 4G cellular. It operates within a frequency range of 862 to 1020 MHz. The drone's configuration includes essential components such as electronic speed controllers, motors, propellers, a flight controller (Pixhawk-4), a BME280 sensor, a battery, a Raspberry Pi 3 microcontroller, and the LoRa module. As shown in Figure 9, the LoRa module installed on the drone employs a 4G transceiver to establish communication between the ground server gateway and the cloud. This setup, with the gateway server acting as the interface between a wide area containing numerous nodes and the cloud, ensures the reliable transmission of data from the farm's sensors to the cloud even in remote and challenging environments.

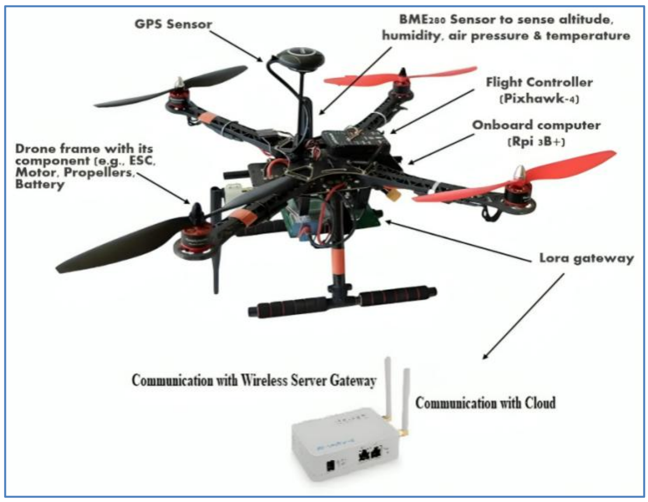

Fig. 8. Drone–LoRa gateway.

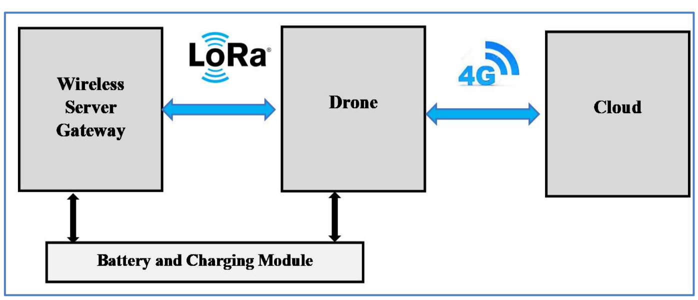

Fig. 9. . Block diagram of the drone–LoRa gateway

11.4. Cloud Layer

Cloud computing plays a vital role in processing and storing data. It offers storage, analytics resources, and web services. The cloud processes data for visualization, analytics, decision-making, and more.

11.5. End-User Layer

This layer represents the ground station controlled by an admin user. It communicates with the drone and provides control over its flight and functions. The Hata empirical propagation path loss model is used to optimize signal propagation from the drone to terrestrial sensors, improving reliability, mobility, and power consumption.

In summary, the platform integrates a variety of sensors for data collection, uses LoRa technology for data transmission, and employs a drone as a mobile gateway to connect remote sensors with the cloud. The cloud layer processes and stores

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the data, and the end-user layer facilitates control and communication with the drone. This comprehensive architecture aims to enhance decision-making and farm productivity in smart agriculture.

12. ANALYSIS OF RESULTS AND DATA

This research was conducted with the aim of investigating the factors that affect the acceptance of the proposed new technology in agriculture using the Internet and drones in Iraq by using the UTAUT model.

12.1. IoT Data Analysis

1. This process aims to investigate the factors that influence the acceptance of new technology in agriculture by using the IoT and drones in Iraq.
2. The UTAUT model was used to analyze and understand the influencing factors of technology acceptance.
3. Quantitative research methods and structural equation modeling were employed to analyze data and verify the proposed hypotheses.
4. Data were collected through an online survey and distributed to the target population.
5. A total of 140 valid surveys were collected, including demographic and behavioral information from respondents.
6. The survey consists of two parts: the first part relates to demographic and behavioral information of the respondents, and the second part is related to measuring the compatibility with the respondents on the basis of the proposed model.
7. Responses were measured using a five-point Likert scale to assess the compatibility of the independent and dependent variables in the proposed model.
8. The independent variables for the Five constructs are performance expectancy, effort expectancy, social influence, facilitating conditions, and behavioral intention.
9. A total of 20 items were measured in the survey.
10. Several core hypotheses were defined, including the expected impact of the independent variables on the behavioral intention to use the proposed new technology in the agricultural sector.

12.2 Descriptive Statistics and Demographic Variables

This section reviews and evaluates information related to personal characteristics and demographic results of the 130 research participants.

- **Gender:** Fifty-two individuals (40.0%) were female, and 78 individuals (60.0%) were male.

- **Age**: Twenty-four individuals (18.5%) were under 30 years old, 54 individuals (41.5%) were between 31 and 40 years old, 23 individuals (17.7%) were between 41 and 50 years old, and 29 individuals (22.3%) were above 50 years old.

- **Education Level:** Forty-seven individuals (36%) were experts, 67 individuals (51.5%) held a master’s degree, 13 individuals (10%) held a doctoral degree, and 3 individuals (2.3%) had education levels beyond a doctoral degree. Most of the participants were experts and senior experts.

- **Type of Work:** Forty-eight individuals (9.36%) worked in the private sector, 67 individuals (51%) worked in public institutions, and 15 individuals (11.5%) worked in joint ventures (both private and public sectors).

- **Work Experience:** Thirty-two individuals (24.6%) had less than five years of work experience, 23 individuals (17.7%) had between 5 and 10 years of work experience, 50 individuals (38.5%) had between 10 and 15 years of work experience, and 25 individuals (19.2%) had more than 15 years of work experience.

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12.3. Descriptive Statistics for Research Questions

- Depending on the number of different survey participants' responses to each question, the result of the number of completely opposite and opposite answers was compared with the other answers for each question.
- This preliminary result is the first step to practicing agriculture using the IoT and drones in Iraq.
- Other descriptive indicators such as mean and standard deviation were determined for all research questions.
- The table shows that the lowest standard deviation is Question 2, which means that the respondents' answers to this question were more consistent than the answers to the other questions.
- Related to Question 18, the highest standard deviation indicates that workers in the agricultural sector and related institutions in Iraq will rely on the smart agriculture platform using the IoT and drones in the next year.
- They have more differences of

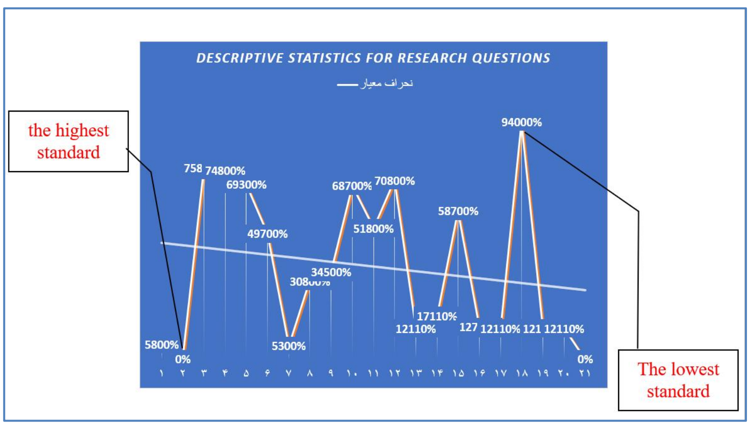

Fig. 10. Descriptive statistics for research questions

12.4. Results

1. The four factors could explain more than 66% of the variance of the items.
2. The validity process was completed successfully, and the validity of the questionnaire was confirmed.
3. In the second stage, the total variance increased slightly.
4. The internal reliability of the questionnaire shows excellent consistency according to the Cronbach's alpha coefficient.
5. A significant correlation exists between all factors, effort and performance expectations, social influence, facilitating conditions, and behavioral intention.

12.5. Current Trends and Future Challenges

To clarify the current state, we recognize that a new type of transformation is occurring in the agricultural industry. Agriculture has moved on from the legacy decision support systems equipped with a predefined time scheduling function in most of the cases to a new era of cultivation systems that include various innovative technologies such as IoT, UAV, AI, and machine learning. The key issue for the large-scale penetration of IoT technology in agriculture will be the improvement of cultivation practices that limit the specific goals of the farmers. UAV technology was first introduced in agriculture for remote monitoring and observation.

Several complex agriculture issues are addressed in an early stage by the utilization of UAV technology in the field. The agricultural industry, and consequently the agricultural economy, is undoubtedly a highly challenging ecosystem of the global economy with high potential. Therefore, key emerging technologies such as IoT and UAV are expected to play a pivotal role in the future.

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13. RESEARCH PROPOSALS AND RECOMMENDATIONS

13.1 Conclusions

1. The IoT and its applications in agriculture are highly significant.
2. Drones and various communication protocols offer advantages in agricultural applications.
3. Smart agriculture encompasses techniques such as precision farming, greenhouse cultivation, and urban agriculture.
4. Developing countries are taking steps to address challenges related to climate change, water scarcity, and food security.
5. IoT and UAVs have enabled sustainable smart farming, enhanced the crop quality, and reduced the environmental impact.
6. A low-cost platform for real-time environmental monitoring using IoT sensors and drones has been proposed.
7. This platform aids in predicting environmental conditions, thereby improving crop productivity and farm management.
8. Meeting the food demands of a growing population requires smarter and more efficient crop production methods.

13.2 Recommendations

1. Smart and efficient methods of crop production need to be developed to address the issues of shrinking agricultural land and increasing food demand.
2. Awareness of food security should be promoted, and young people should be encouraged to consider agriculture as a legitimate profession.
3. Scientists and engineers should be directed toward current challenges and future prospects in the field of agriculture and the IoT.
4. The platform should be implemented on the ground and expanded to include livestock to create a smart farm platform.
5. Machine learning and AI techniques can be used to extract valuable patterns and trends to improve crop production and reduce waste on the basis of data analysis.
6. Strong security measures must be adopted to protect farm data and ensure that Internet-connected systems are not compromised.
7. Awareness and training programs should be provided for farmers and workers in the agricultural field to understand and use the smart platform effectively.

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