Data-Driven Precision Agriculture Advanced Irrigation System for Sustainable Smart Farming

Akram Ghilan
Laboratory: Engineering, Systems, and Applications, (LESA)
ENSA of Fez, Sidi Mohamed Ben Abdellah University
Fez 28810, Morocco
ghilan2akram@gmail.com

Youssef EL AFOU
Laboratory: Engineering, Systems, and Applications, (LESA)
ENSA of Fez, Sidi Mohamed Ben Abdellah University
Fez 28810, Morocco
youssef.elafou@usmba.ac.ma

Mostafa MERRAS
IMAGE Laboratory,
High School of Technology, Moulay Ismail University,
Meknes 50050, Morocco
merras.mostafa@gmail.com

Nabil El Akkad
Laboratory: Engineering, Systems, and Applications, (LESA)
ENSA of Fez, Sidi Mohamed Ben Abdellah University
Fez 28810, Morocco
nabil.elakkad@usmba.ac.ma

2024 4th International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET) | 979-8-3503-0950-8/24/$31.00 ©2024 IEEE | DOI: 10.1109/IRASET60544.2024.10548267

***Abstract*—Precision Agriculture (PA) is a farming management strategy that leverages digital technologies and techniques to monitor and optimize agricultural production processes. By utilizing data streams from satellites, mobile phones, the Internet of Things (IoT), and technologies like cloud computing and artificial intelligence, PA has the potential to improve the quantity and quality of agricultural outputs while reducing inputs and waste. This article presents a proposed irrigation system for PA in the field of smart farming. The system incorporates a diverse set of sensors, including soil moisture and temperature sensors, air humidity and temperature sensors, water level sensors, and light sensors. It also integrates weather data from a forecasting platform, encompassing variables such as wind speed, wind direction, and weather status. By collecting and analyzing field-specific data alongside weather forecasts, the system enables precise and sustainable watering practices. The data is stored, analyzed, and visualized using a ThingSpeak platform, providing farmers with valuable insights to make informed irrigation decisions.**

Keywords—Internet of Things (IoT), Agriculture, Agriculture IoT, Precision agriculture, Smart Farming, ThingSpeak, Precision Farming, Smart Irrigation.

I. Introduction

Several fields have seen remarkable progress, such as precision agriculture, security [1-5], and computer vision [6-13] due to the powerful rise of the Internet of Things approaches and artificial intelligence algorithms. Precision Agriculture (PA), also referred to as precision farming or smart farming [14], represents a pivotal shift in contemporary agriculture, stands at the forefront of modern farming, revolutionizing traditional agricultural practices through the integration and the judicious utilization of digital technologies and innovative techniques [15-18]. This farming management strategy harnesses the power of data derived from diverse sources such as remote sensing technologies, mobile phones, wireless sensor networks (WSN), the Internet of Things (IoT), cloud computing, and artificial intelligence to optimize and monitor agricultural production processes [15], [17], [19-23]. By leveraging this intricate network of information, PA holds the promise of enhancing both the quantity and quality of agricultural outputs while simultaneously minimizing resource inputs and waste [24], [25]. This technology-driven approach enables farmers to make informed decisions with a heightened degree of accuracy, optimizing the allocation of critical resources, including water [25-28], fertilizers, and pesticides. By harnessing real-time data and insights, PA allows farmers to minimize waste, reduce environmental impacts, and simultaneously bolster crop yields. Such advancements in resource management have the potential to not only safeguard food security but also foster sustainable agricultural practices [29], [30]. The transformative implications of advanced information and communication technologies applications in PA are profound, warranting a closer examination. Looking towards the future there is a lot of promise when it comes to information and communication technologies in PA. Innovations, like IoT, artificial intelligence, and machine learning are constantly pushing the boundaries of what we can achieve in this field [15], [18], [31]. The emergence of farm machinery, robotics, and interconnected agricultural ecosystems adds more potential for automation reducing the need for manual labor and improving overall efficiency. Additionally, the seamless integration of Big Data and cloud-based platforms opens up opportunities for collaboration and knowledge sharing among data-driven farmers [15], [31-33]. overall, the convergence of advanced Information and Communication Technologies with the agricultural sector holds profound implications for the future of farming [34].

Therefore, this document delves into the realm of smart farming, proposing an advanced irrigation system tailored for PA. The system is meticulously designed, incorporating an array of sensors that capture crucial environmental parameters. Furthermore, it seamlessly integrates real-time weather data obtained from a forecasting platform, encompassing variables such as wind speed, wind direction, and overall weather status.

The cornerstone of this proposed irrigation system lies in its ability to collect and analyze field-specific data alongside weather forecasts. This synergy empowers farmers to implement precise and sustainable watering practices, optimizing resource utilization and fostering environmentally conscious agricultural operations. The collected data is not merely stored but undergoes comprehensive analysis and visualization through the utilization of the ThingSpeak platform. This integration equips farmers with actionable insights, enabling informed decisions that transcend conventional irrigation strategies and pave the way for a more efficient and sustainable future in agriculture.. The rest of this paper is organized as follows: the second part present the IoT and WSN in agriculture, The proposed method is discussed in the third part and it also present the components of the proposed system, The experiments and result are presented in the fourth part, the discussions in the fifth part, and the conclusion in the last part.

II. IoT AND WSN IN AGRICULTURE

IoT and WSN technologies [22] have revolutionized agriculture by offering real-time monitoring, automation, and data analysis. These tools optimize productivity, resource utilization, and decision-making for better yields and sustainability. Automation is facilitated by IoT and WSN, automating tasks like irrigation and pest control [30], [33], [35]. Real-time data from sensors allows precise resource allocation, reducing human intervention, saving time, and improving efficiency.

Data analysis is vital, leveraging IoT and WSN data for insights on crop health, disease detection, yield prediction, and resource allocation [14], [20], [28], [32]. Farmers can make proactive decisions, detect anomalies, and optimize practices using predictive analytics.

IoT and WSN enable remote monitoring and management of agricultural operations through mobile apps or web-based dashboards [29], [33]. Farmers can access real-time data, make informed decisions, and ensure smooth farm operation from anywhere. Benefits of IoT in agriculture include real-time monitoring of soil moisture, temperature, humidity, and light intensity [23], [31], [33]. This data is wirelessly transmitted for analysis, enabling informed decisions such as timely irrigation to optimize water usage and crop conditions [14], [36-38].

In summary, IoT and WSN have transformed agriculture by providing real-time monitoring, automation, and data analysis. These technologies optimize resource usage, increase productivity, and drive sustainable farming practices. The future of agriculture holds even greater potential to address food security, environmental sustainability, and productivity challenges.

III. MATERIALS AND METHODS

A. *the proposed method*

The proposed system establishes interconnections among multiple sensors to facilitate comprehensive data collection. The acquired data will be transmitted to a web-based platform for meticulous analysis and visualization, exemplified in the accompanying figures.

Within this framework, a novel Internet of Things (IoT)-based agricultural instrument has been developed for real-time monitoring of soil temperature and moisture, water levels, and light consumption by plants, leveraging the capabilities of the ESP32 board. The entire spectrum of sensor data is seamlessly conveyed to the ThingSpeak platform, renowned for its efficacy in supporting ESP32-based IoT pro-jects. Through the user-friendly interface of ThingSpeak, data monitoring becomes accessible from any location with internet connectivity, owing to the built-in WIFI module with the ESP32 board that ensures internet connectivity. Within the intuitive interface of ThingSpeak, an additional layer of analytical depth is facilitated through the incorporation of MATLAB scripting capabilities. This feature empowers users with the ability to conduct intricate and tailored analyses. The MATLAB scripts seamlessly execute on the ThingSpeak platform, expanding data collection to encompass diverse weather parameters such as wind speed, direction, precipitation, and cloud cover. This holistic data aggregation is achieved through the integration of APIs from OpenWeatherMap, a reliable source for weather fore-casting.

The proposed agricultural prototype is poised to significantly benefit farmers by augmenting agricultural yield and enhancing the efficiency of food production. This is achieved by providing farmers with continuous access to precise climate conditions, soil moisture levels, and other pertinent parameters. Such accurate and real-time information equips farmers with the tools necessary to make informed decisions, ultimately contributing to the optimization of agricultural processes.

B. *Proposed system overview*

The proposed system consists of two parts, the first part is to connect the different sensors and actuators used with the esp32 board and send data to ThingSpeak, the second is to store and analyze data that can be visualize and accessible via the Inter-net using a browser as shown in Fig.1.

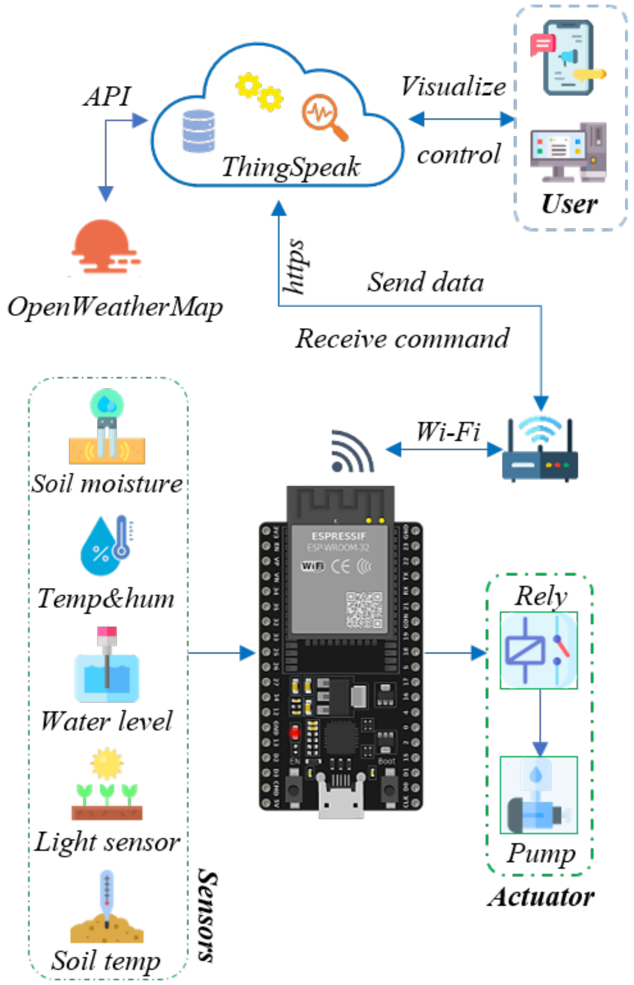

Fig. 1. proposed system architecture

This connection's main goal is to gather the values of environmental variables, which will help with decision making related to scheduling irrigation and figuring out the amount of water is necessary for plants

C. Main diagram

In figure fig.2. below the main diagram of the proposed system. We will use a programmable microcontroller board esp32, a relay for controlling the irrigation pump, and physical phenomena sensors to collect data on soil moisture, and temperature, water level, air temperature, and humidity, and light consumed by plants.

The ESP32 board is programmed by Arduino core for the ESP32, this programming allows us to acquire and collect the data from the sensors and display it when needed.

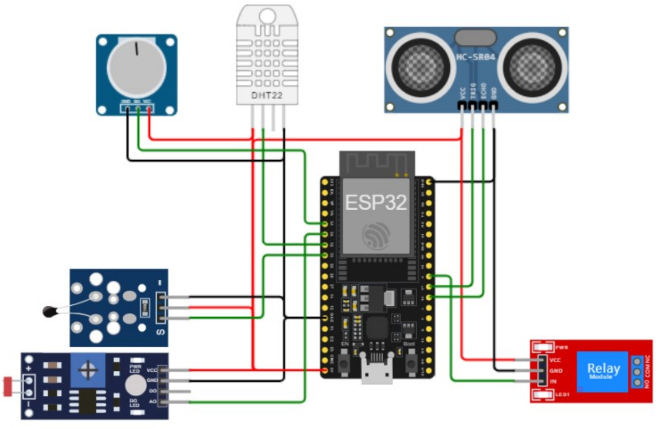

Fig. 2. Main diagram

To make this data accessible from the internet, we use the built-in Wi-Fi model to connect our ESP32 board to the internet and send the sensor data to ThingSpeak platform.

To analyze the various physical parameters, we continuously collect data using WIFI enabled IOT sensors and then it is uploaded into ThingSpeak. The stored data is fed into ThingSpeak for analysis; ThingSpeak continuously reads the data and visualizes it on graphs.

The system's hardware main components are an ESP32 microcontroller, moisture sensor, temperature and humidity sensor(dht22), soil temperature sensor, and relay.

1) Microcontroller ESP32

The ESP32 is a versatile microcontroller by Espressif Systems, widely used in IoT due to its multitasking ability, built-in Wi-Fi and Bluetooth, and compatibility with various peripherals and development environments.

2) ThingSpeak

ThingSpeak, an IoT analytics platform service that offers a versatile platform for IoT data analysis, with features that allow data transfer from different devices, real-time data visualization, and alert generation using web services. Furthermore, integrating MATLAB Analytics within ThingSpeak provides a powerful environment for executing MATLAB code for data preprocessing, visualizations, and analyses.

IV. EXPERIMENTS AND RESULT

The proposed system's overall aim is to enhance the effective implementation of an IoT System for irrigation process in Precision Agriculture applications. It provides guidelines and practices for IoT development and implementation practitioners. To validate the proposed system, we used an online Electronics simulator (Wokwi) it uses to simulate Arduino, ESP32, STM32, and many other popular boards, parts and sensors.

A. Simulation

From the tests by running the simulation process, and based on the results of these tests, the ESP32 managed to send data continuously to ThingSpeak all controlled durations. The data is sent in the form of the temperature in degrees Celsius, the water level, the measure of the light intensity to which it is exposed, and the percentage of humidity and soil moisture. Examples of data sent are in Fig.3.

```
soil moisture:81% | soil temperture:33.40°C
Temp: 25.10°C | Humidity: 68.0%
Water level:231.96cm | light:499.63lux
Channel update successful.
soil moisture:81% | soil temperture:33.40°C
Temp: 25.10°C | Humidity: 68.0%
Water level:231.96cm | light:100.01lux
Channel update successful.
soil moisture:52% | soil temperture:33.40°C
Temp: 14.50°C | Humidity: 84.0%
Water level:231.96cm | light:100.01lux
Channel update successful.
```

Fig. 3. Data sent by ESP32

All previously collected data is sent to ThingSpeak, and from ThingSpeak, the data can be viewed from a URL that visualizes the data graphically. The graphs obtained represent the data of each term measured as a function of time. Also, the data fetched from the weather forecasting platform The figures below fig.4 and fig.5 show the soil temperature and moisture data displayed respectively in graphical form through ThingSpeak

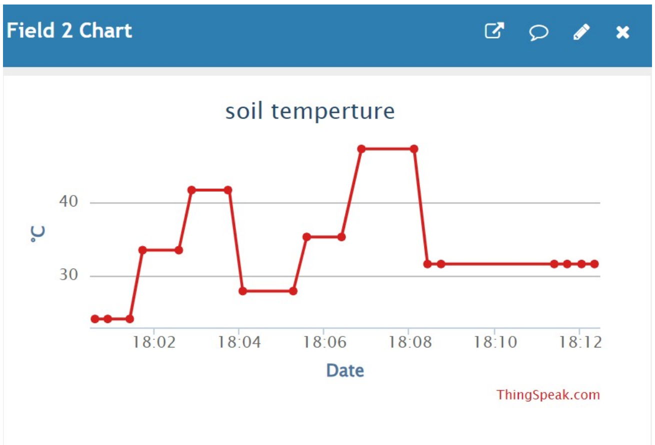

Fig. 4. Soil temperature graph

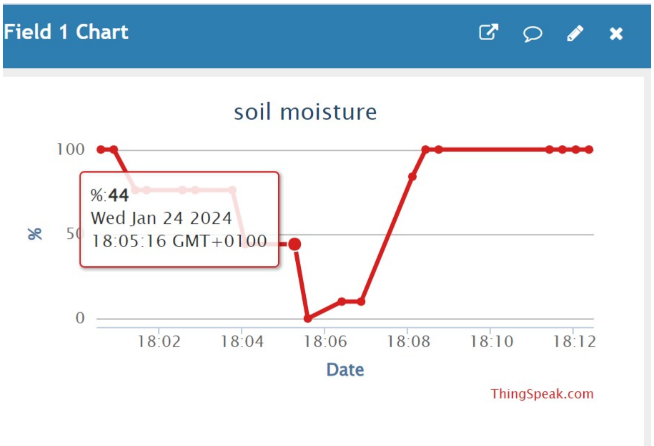

Fig. 5. Soil moisture graph

The figures below fig.6. and fig.7. represent the air temperature and humidity data displayed respectively in graphical form through ThingSpeak.

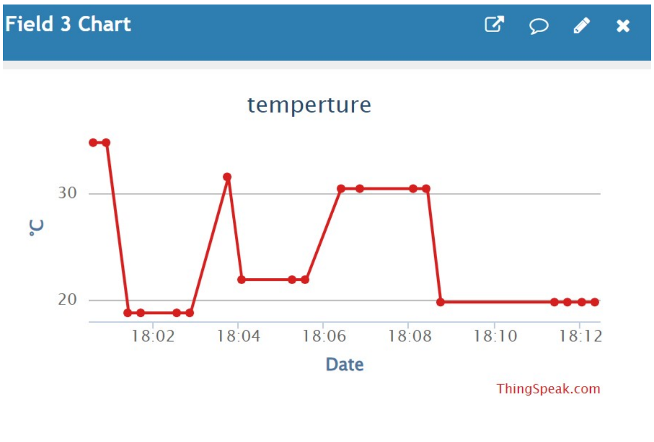

Fig. 6. Termperature graph

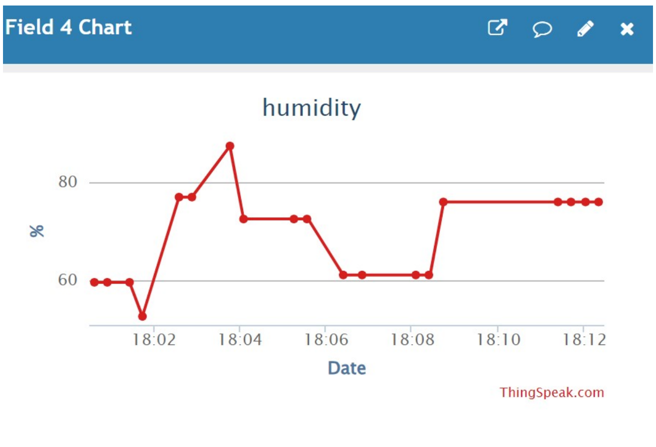

Fig. 7. Air Humidity graph

The figure below fig.8. represent the illumination data displayed in graphical form through ThingSpeak.

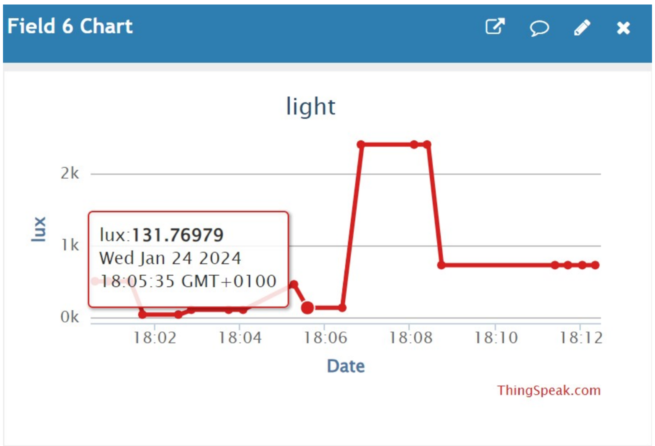

Fig. 8. Light graph

The figure fig.9. represent the water level data displayed in graphical form through ThingSpeak.

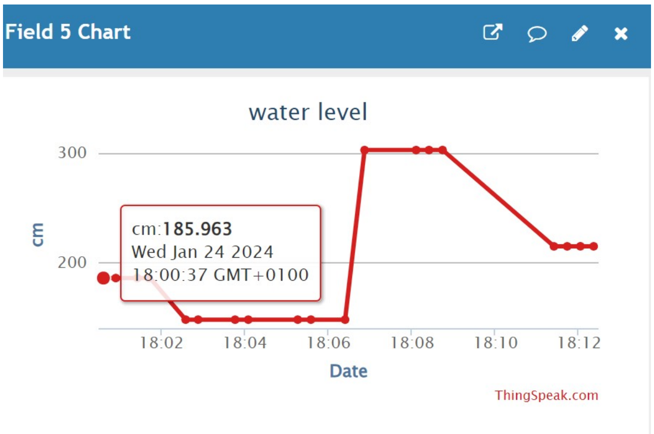

Fig. 9. Water level graph

The figure below fig.10. represent the current wind speed and direction data fetched from openweathermap and displayed in graphical form through ThingSpeak.

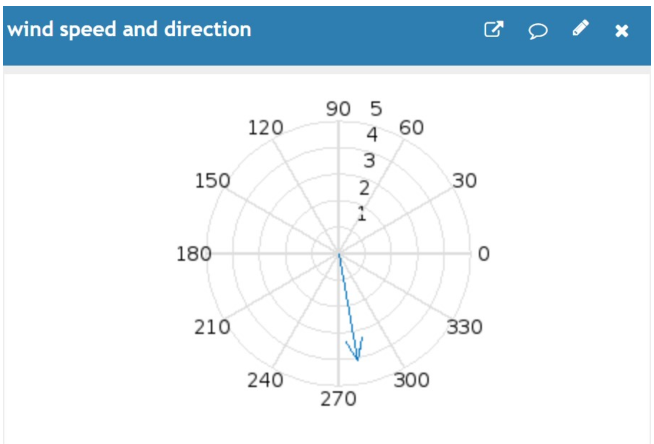

Fig. 10. Wid speed and direction

V. DISCUSSIONS

The proposed precision irrigation system in the field of smart farming holds significant potential for improving agricultural production processes. Utilizing digital technologies and integrating various sensors, weather data, and advanced analytics, the system aims to enable precise and sustainable watering practices. In this section, we will discuss the implications, benefits, and challenges associated with the implementation of such a system.

One of the key benefits of the proposed system is its ability to utilize a diverse set of sensors to collect Real-time field-specific data, The inclusion of soil moisture and temperature sensors, air humidity and temperature sensors, water level sensors, and light sensors provides comprehensive information about the environmental conditions. This data combined with weather forecasts, allows farmers to make informed irrigation decisions, minimizing water wastage and improving crop yield.

Moreover, the integration of weather data from a forecasting platform improves the system's capabilities by considering wind speed, direction, and weather status. This allows the system to adjust irrigation schedules, such as delaying when high wind speeds to prevent water loss and conserving water resources.

The use of cloud computing enhances data storage, analysis, and visualization, providing valuable insights for farmers.

Challenges include cost, farmer adoption, and data accuracy, which need to be addressed for successful implementation. Overall, this system has the potential to revolutionize agriculture by enhancing efficiency and sustainability.

VI. CONCLUSION

This document presents a new IoT-based agriculture tool for live monitoring of soil temperature and soil moisture, water level, air temperature and humidity, and light has been processed using ESP32 microcontroller. All of these sensor values are sent to ThingSpeak which provides a very good tool for IoT-based projects. Through the ThingSpeak platform, we can monitor our data on the internet from anywhere using the internet, this system is connected to the internet using ESP32 built-in Wi-Fi.

The proposed irrigation system will help the farmers to increase the yield of agriculture and deal with food production efficiently, as it will always be useful for them to get an accurate supply of the environmental temperature soil moisture and other parameters with more precision in the results.

REFERENCES

[1] H. Touil, N. el Akkad, and K. Satori, "H-Rotation: Secure Storage and Retrieval of Passphrases on the Authentication Process," *Int. J. Saf. Secur. Eng.*, vol. 10, pp. 785–796, Dec. 2020, doi: 10.18280/ijsse.100609.

[2] H. Touil, N. el Akkad, and K. Satori, "Secure and Guarantee QoS in a Video Sequence: A New Approach Based on TLS Protocol to Secure Data and RTP to Ensure Real-Time Exchanges," *Int. J. Saf. Secur. Eng.*, vol. 11, pp. 59–68, Feb. 2021, doi: 10.18280/ijsse.110107.

[3] M. Es-Sabry, N. el Akkad, M. Merras, A. Saaidi, and K. Satori, "A New Color Image Encryption Algorithm Using Multiple Chaotic Maps with the Intersecting Planes Method," *Sci. Afr.*, vol. 16, p. e01217, May 2022, doi: 10.1016/j.sciaf.2022.e01217.

[4] F. E. Azzaby, N. E. Akkad, K. Sabour, and S. Kabbaj, "A new encryption scheme for RGB color images by coupling 4D chaotic laser systems and the Heisenberg group," *Multimed. Tools Appl.*, vol. 83, no. 8, pp. 24633–24652, Mar. 2024, doi: 10.1007/s11042-023-16139-6.

[5] M. Es-sabry *et al.*, "An efficient 32-bit color image encryption technique using multiple chaotic maps and advanced ciphers," *Egypt. Inform. J.*, vol. 25, p. 100449, Mar. 2024, doi: 10.1016/j.eij.2024.100449.

[6] M. Merras, N. E. Akkad, A. Saaidi, A. G. Nazih, and K. Satori, "Camera Self Calibration with Varying Parameters by an Unknown Three Dimensional Scene Using the Improved Genetic Algorithm," *3D Res.*, vol. 6, no. 1, p. 7, Feb. 2015, doi: 10.1007/s13319-015-0039-6.

[7] S. El Hazzat, M. Merras, N. El Akkad, A. Saaidi, and K. Satori, "Enhancement of sparse 3D reconstruction using a modified match propagation based on particle swarm optimization," *Multimed. Tools Appl.*, vol. 78, no. 11, pp. 14251–14276, Jun. 2019, doi: 10.1007/s11042-018-6828-1.

[8] N. E. Akkad, M. Merras, A. Saaidi, and K. Satori, "ROBUST METHOD FOR SELF-CALIBRATION OF CAMERAS HAVING THE VARYING INTRINSIC PARAMETERS," . *Vol.*, vol. 50, 2005.

[9] B. Boudine, S. Kramm, N. E. Akkad, A. Bensrhair, A. Saaidi, and K. Satori, "A flexible technique based on fundamental matrix for camera self-calibration with variable intrinsic parameters from two views," *J. Vis. Commun. Image Represent.*, vol. 39, pp. 40–50, Aug. 2016, doi: 10.1016/j.jvcir.2016.05.003.

[10] N. El Akkad, A. Saaidi, and K. Satori, "Self-calibration based on a circle of the cameras having the varying intrinsic parameters," in *2012 International Conference on Multimedia Computing and Systems*, May 2012, pp. 161–166. doi: 10.1109/ICMCS.2012.6320196.

[11] L. Khrissi, N. E. Akkad, H. Satori, and K. Satori, "An Efficient Image Clustering Technique based on Fuzzy C-means and Cuckoo Search Algorithm," *Int. J. Adv. Comput. Sci. Appl. IJACSA*, vol. 12, no. 6, Art. no. 6, 30 2021, doi: 10.14569/IJACSA.2021.0120647.

[12] M. Merras, A. Saaidi, N. El Akkad, and K. Satori, "Multi-view 3D reconstruction and modeling of the unknown 3D scenes using genetic algorithms," *Soft Comput.*, vol. 22, no. 19, pp. 6271–6289, Oct. 2018, doi: 10.1007/s00500-017-2966-z.

[13] M. Merras, N. E. Akkad, A. Saaidi, G. Nazih, and K. Satori, "Camera Calibration with Varying Parameters Based On Improved Genetic Algorithm," vol. 13, 2014.

[14] E. Anastasiou *et al.*, "Precision farming technologies for crop protection: A meta-analysis," *Smart Agric. Technol.*, vol. 5, p. 100323, Oct. 2023, doi: 10.1016/j.atech.2023.100323.

[15] S. A. Bhat and N.-F. Huang, "Big Data and AI Revolution in Precision Agriculture: Survey and Challenges," *IEEE Access*, vol. 9, pp. 110209–110222, 2021, doi: 10.1109/ACCESS.2021.3102227.
[16] R. P. dos Santos, N. Fachada, M. Beko, and V. R. Q. Leithardt, "A Rapid Review on the Use of Free and Open Source Technologies and Software Applied to Precision Agriculture Practices," *J. Sens. Actuator Netw.*, vol. 12, no. 2, Art. no. 2, Apr. 2023, doi: 10.3390/jsan12020028.
[17] S. M. Z. A. Naqvi *et al.*, "Role of 5G and 6G Technology in Precision Agriculture," in *PAPC 2022*, MDPI, Nov. 2022, p. 3. doi: 10.3390/environsciproc2022023003.
[18] S. Bouarourou, E. habib Nfaoui, A. Boulalaam, and A. Zannou, "A Predictive Model for Abnormal Conditions in Smart Farming using IoT Sensors," *Procedia Comput. Sci.*, vol. 230, pp. 248–256, Jan. 2023, doi: 10.1016/j.procs.2023.12.080.
[19] M. M. Awad, "Toward Precision in Crop Yield Estimation Using Remote Sensing and Optimization Techniques," *Agriculture*, vol. 9, no. 3, Art. no. 3, Mar. 2019, doi: 10.3390/agriculture9030054.
[20] R. Togneri, R. Prati, H. Nagano, and C. Kamienski, "Data-driven water need estimation for IoT-based smart irrigation: A survey," *Expert Syst. Appl.*, vol. 225, p. 120194, Sep. 2023, doi: 10.1016/j.eswa.2023.120194.
[21] F. Z. Bassine, T. E. Epule, A. Kechchour, and A. Chehbouni, "Recent applications of machine learning, remote sensing, and iot approaches in yield prediction: a critical review." arXiv, Jun. 07, 2023. Accessed: Dec. 06, 2023. [Online]. Available: http://arxiv.org/abs/2306.04566
[22] L. Kumar1, P. Ahlawat, P. Rajput, R. I. Navsare, and P. Kumar Singh, "INTERNET OF THINGS (IOT) FOR SMART PRECISION FARMING AND AGRICULTURAL SYSTEMS PRODUCTIVITY: A REVIEW," *Int. J. Eng. Appl. Sci. Technol.*, vol. 5, no. 9, Jan. 2021, doi: 10.33564/IJEAST.2021.v05i09.022.
[23] L. García *et al.*, "Deployment Strategies of Soil Monitoring WSN for Precision Agriculture Irrigation Scheduling in Rural Areas," *Sensors*, vol. 21, no. 5, Art. no. 5, Mar. 2021, doi: 10.3390/s21051693.
[24] N. S. Abu *et al.*, "Internet of Things Applications in Precision Agriculture: A Review," *J. Robot. Control JRC*, vol. 3, no. 3, Art. no. 3, May 2022, doi: 10.18196/jrc.v3i3.14159.
[25] G. S. Prasanna Lakshmi, P. N. Asha, G. Sandhya, S. Vivek Sharma, S. Shilpashree, and S. G. Subramanya, "An intelligent IOT sensor coupled precision irrigation model for agriculture," *Meas. Sens.*, vol. 25, p. 100608, Feb. 2023, doi: 10.1016/j.measen.2022.100608.
[26] L. García, L. Parra, J. M. Jimenez, J. Lloret, and P. Lorenz, "IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture," *Sensors*, vol. 20, no. 4, Art. no. 4, Feb. 2020, doi: 10.3390/s20041042.
[27] M. K. Saggi and S. Jain, "A Survey Towards Decision Support System on Smart Irrigation Scheduling Using Machine Learning approaches," *Arch. Comput. Methods Eng.*, vol. 29, no. 6, pp. 4455–4478, Oct. 2022, doi: 10.1007/s11831-022-09746-3.
[28] E. Bwambale, F. K. Abagale, and G. K. Anornu, "Data-Driven Modelling of Soil Moisture Dynamics for Smart Irrigation Scheduling," *Smart Agric. Technol.*, vol. 5, p. 100251, Oct. 2023, doi: 10.1016/j.atech.2023.100251.
[29] A. Morchid, R. El Alami, A. A. Raezah, and Y. Sabbar, "Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges," *Ain Shams Eng. J.*, vol. 15, no. 3, p. 102509, Mar. 2024, doi: 10.1016/j.asej.2023.102509.
[30] A.-F. Jimenez, P.-F. Cardenas, A. Canales, F. Jimenez, and A. Portacio, "A survey on intelligent agents and multi-agents for irrigation scheduling," *Comput. Electron. Agric.*, vol. 176, p. 105474, Sep. 2020, doi: 10.1016/j.compag.2020.105474.
[31] M. San Emeterio de la Parte, J.-F. Martínez-Ortega, V. Hernández Díaz, and N. L. Martínez, "Big Data and precision agriculture: a novel spatio-temporal semantic IoT data management framework for improved interoperability," *J. Big Data*, vol. 10, no. 1, p. 52, Apr. 2023, doi: 10.1186/s40537-023-00729-0.
[32] L. Rabhi, N. Falih, L. Afraites, and B. Bouikhalene, "Digital agriculture based on big data analytics: a focus on predictive irrigation for smart farming in Morocco," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 24, no. 1, p. 581, Oct. 2021, doi: 10.11591/ijeecs.v24.i1.pp581-589.
[33] B. Badrun and M. Manaf, "The Development of Smart Irrigation System With IoT, Cloud, and Big Data," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 830, no. 1, p. 012009, Sep. 2021, doi: 10.1088/1755-1315/830/1/012009.
[34] U. Sarkar, G. Banerjee, and I. Ghosh, "Artificial intelligence in agriculture: Application trend analysis using a statistical approach," *Int. J. Appl. Sci. Eng.*, vol. 20, no. 1, pp. 1–8, 2022, doi: 10.6703/IJASE.202303_20(1).002.
[35] M. Pramanik *et al.*, "Automation of soil moisture sensor-based basin irrigation system," *Smart Agric. Technol.*, vol. 2, p. 100032, Dec. 2022, doi: 10.1016/j.atech.2021.100032.
[36] E. M. Raouhi, M. Zouizza, M. Lachgar, Y. Zouani, H. Hrimech, and A. Kartit, "AIDSII: An AI-based digital system for intelligent irrigation," *Softw. Impacts*, vol. 17, p. 100574, Sep. 2023, doi: 10.1016/j.simpa.2023.100574.
[37] C. Jamroen, P. Komkum, C. Fongkerd, and W. Krongpha, "An Intelligent Irrigation Scheduling System Using Low-Cost Wireless Sensor Network Toward Sustainable and Precision Agriculture," *IEEE Access*, vol. 8, pp. 172756–172769, 2020, doi: 10.1109/ACCESS.2020.3025590.
[38] M. S. Munir, I. S. Bajwa, A. Ashraf, W. Anwar, and R. Rashid, "Intelligent and Smart Irrigation System Using Edge Computing and IoT," *Complexity*, vol. 2021, p. e6691571, Feb. 2021, doi: 10.1155/2021/6691571.