A Solar-Powered Automated Irrigation System Using Arduino and Moisture Sensors for Efficient Water Management in Agriculture

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ABSTRACT

As agriculture is the primary source of food in many countries, effective irrigation systems are crucial. This article presents a system that can regulate irrigation based on demand using Arduino Uno, a solar-powered water pump, and an autonomous water flow control system with a moisture sensor to reduce water consumption and time. Traditional irrigation methods often lead to inefficient water use due to a lack of real-time monitoring and control, especially in regions with limited water resources. In addition, manual irrigation systems are time-consuming and can result in over- or under-irrigation, affecting crop yield and resource management. With increasing concerns about water scarcity and the need for sustainable agriculture, there is a critical need for automated irrigation solutions that are both energy-efficient and cost-effective. The proposed system aims to optimize water usage based on soil conditions in real time. This system can be applied to farms, parks, and other locations that require efficient irrigation systems. The proposed approach supports aggressive water management for agricultural land, reduces power costs, is cheap, has a small size, and is highly adaptable. This system is especially beneficial for farmers and gardeners who may not have the time or resources for regular irrigation. Assessing real-time soil moisture levels can ensure that crops receive optimal water supply based on actual needs.

Keywords-agriculture; irrigation system; Arduino UNO; moisture sensor; automatic irrigation; low power; energy efficiency

I. INTRODUCTION

Solar-powered systems are sustainable and environmentally friendly since they use the energy of the sun, which is a renewable resource. Automatic irrigation systems regulate water consumption by providing plants with the exact amount of water they require. Irrigation systems can use solar power as a decentralized and independent energy source, reducing the dependence on traditional grids, which makes it appropriate for isolated or off-grid agricultural regions. Since solar energy is a sustainable and clean substitute for fossil fuels, solar-powered irrigation systems can help reduce greenhouse gas emissions. Solar-powered automatic irrigation systems can be programmable and monitorable, creating ideal conditions for plant growth and increasing crop yields. Installing solar-powered irrigation systems in rural regions can boost agricultural growth and farmers' standards of living. Many studies have proposed the use of sensor technology to track soil moisture content and weather patterns. Sophisticated algorithms and control systems have been proposed to improve water usage and ensure that crops receive the appropriate amount of water at the appropriate time. Researchers have investigated ways to make solar-powered systems more energy-efficient, such as better solar panel designs, energy storage options, and the incorporation of energy-efficient parts [1].

This study aimed at a multimodal approach to automate the agricultural sector. The entire system is solar-powered, ensuring a source of renewable energy. Throughout its useful lifetime, which can last up to 25 years, solar panel systems are extremely robust and require little to no maintenance. Human intervention can be reduced with automated irrigation equipment. This project provides farmers with an automated irrigation system that allows them to effectively irrigate their farmland. The project is divided into three components: a solar panel, an automatic pump control system, and an automatic irrigation system that uses a moisture sensor. The solar panel collects solar energy to convert and produce electricity to operate the automatic pump control system. The microcontroller receives input from the moisture sensor. If the soil moisture content drops below a set threshold, the system automatically activates the pump. When the water level returns to normal, the pump automatically turns off [2].

As solar-powered pumping systems are environmentally friendly, their application in irrigation has increased. In a pressurized irrigation system, a small 1 HP Photovoltaic (PV) pump can be used to irrigate water. According to experimental findings, the pump can effectively run sprinklers and drippers for good irrigation uniformity. In [3], a concise review was presented to understand the current state of automation in agriculture. In [4], a smart agriculture management and monitoring system was proposed, using wireless sensor networks. In [5], the integration of transaction-based systems with IoT in smart grids was explored, highlighting how the combination of connectivity and decentralized energy management can enhance efficiency and decision-making. This study emphasized the role of real-time data exchange in enabling dynamic and automated energy transactions. In [6], a comprehensive literature review on solar water pumping technology was presented, assessing its economic viability and identifying research gaps or obstacles to its wider adoption. Some PV-assisted water pumping systems have an investment payback period of 4-6 years. This review provides a detailed analysis of SPVWPS published between 1975 and 2014. In [7], the general classification of solar-powered water pumping systems was examined, along with the historical context of solar pumping systems, and significant research initiatives on related topics. This review analyzed and summarized studies on the modeling and dependability of PV water Pumping Systems (PVPS), highlighting a numerical approach to size them. The design process, the modeling approach, the control strategy, the availability of data, and site barriers, such as shadow effects, introduce difficulties in PVPS [8]. In [9], the focus was on the techno-economic study of solar-powered irrigation systems. In [10], the design of an Internet of Things (IoT)-based solar irrigation system was presented. The proposed system used a chip controller with built-in WiFi connectivity and a solar cell connection to provide the required operating power. To prevent the pump from overheating, the controller also examined the level of underground water. In [11], numerous problems were highlighted in conventional irrigation systems, including heavy water and electricity usage, along with complicated wiring. The application demonstrated that technology can save water, improve rice quality and output, and enhance the intelligence of irrigation systems. In [12], these points were improved with the help of a PLC-based intelligent irrigation management system and setup software.

In [13], an automated irrigation system was developed to optimize water use in agriculture. The technology uses a distributed wireless network of temperature and moisture sensors in the root zone of the plant. In addition, a gateway device was used to provide data to an online application, control actuators, and handle sensor data. An algorithm built into the microcontroller-based gateway controlled the amount of water supplied, using temperature and soil moisture thresholds. In [14], a smart renewable energy irrigation system was developed using an algorithm to analyze soil conditions. A class consisting of several functions was created to allow users and the system to read any sensor and enable any actuator. For example, an instance of this class can monitor environmental variables such as temperature, humidity, and soil moisture. In [15], an automated smart irrigation system was proposed, which was connected to multiple sensors, such as DHT and soil moisture sensors, to monitor soil conditions and make decisions about whether to irrigate the farm. Fuzzy logic was used to automate irrigation, and Arduino served as the fundamental controller for all sensors and solenoid valves. According to this study, as the solar panel's voltage was insufficient to operate the pump and batteries to store solar power were expensive, only the Arduino was powered by a solar panel. In [16], the need for human intervention to open and close gates was reduced by deploying an automated IoT-connected gate through a wireless soil moisture sensor network using GSM [16]. Nine soil irrigation events were used to test the system, which increased irrigation efficiency by up to 86.6%.

Solar technology is employed in agriculture at a rapid rate. In [17], a conceptual paradigm for sustainable and inclusive solar irrigation was presented, focusing on ways to reduce costs and increase social access to solar irrigation. The objective is to make this technology environmentally sustainable and equal. This study offers a framework for supporting legislation, policy, and monitoring of solar irrigation initiatives that are economically and environmentally fair, based on examples and observations from various geographic locations. According to [18], government subsidies and decreasing manufacturing costs for PV equipment have popularized the technology and increased farmers' access and interest in it. The most important conclusion of this study is that the implementation of an integrated strategy in practice significantly increases the chance that PV programs will be successful.

In [19], the use of PV electricity in an automated irrigation system was described, using a variety of sensors to determine the ideal amount of water for a particular crop and location. The system can irrigate the fields for a predetermined period of time on a specific day or days of the week. If the soil dries below a predetermined threshold, it can automatically water the field. In [20], smart irrigation systems were presented to deliver the right amount of water in the right place, reducing effort and saving time. The main goal of this project was to develop a circuit that uses an Arduino to monitor the water level in an agricultural field and automatically pump the necessary water in. The primary objective was to monitor and detect water levels in agricultural areas, particularly paddy fields. In [21], a solar-powered pumping system with a battery-buffered arrangement was introduced, reducing the total irrigation cost by 63%. The design and implementation process was made simpler by considering all internal and external interactions using the system modeling language. In [22], the tension of soil water was measured using a tensiometer adapted to resemble a manometer. This system enabled irrigation control with the help of a preprogrammed timer and estimated soil water stress. For an extended period, the circuits can be powered by a 12 V DC storage battery. In [23], a solar-powered irrigation system was developed to replace a diesel-powered irrigation system and reduce carbon dioxide emissions from agricultural sources. In addition, farmers who used solar-powered irrigation systems were shown to use fertilizers more efficiently.

Solar drip irrigation, as suggested in [24], can simultaneously enhance tomato fruit quality and conserve water. This study used correlation and partial least squares analyses. Accumulated environmental stress impacts tomato fruit quality. Gains in fruit quality under drip irrigation were caused by combined environmental factors, including decreased soil water content, increased air and soil temperature, and the difference between day and night temperatures. In [25], it was shown that solar water pumping systems necessitate evaluating both financial and environmental sustainability and that regulations governing groundwater pumping must be linked to solar pumping subsidies. Solar irrigation plans must take into account groundwater availability and depletion. Data and monitoring are required to improve assessments of impacts on water resources.

In [26], a model was developed to estimate the amount of water required for a given field over a given period of time. The model also included field-specific water consumption data that were stored in the cloud. When the soil moisture content fell below a predetermined level, a microcontroller in the soil moisture sensor turned on a pump. The model in [27] determined the amount of water required for irrigation, efficiently regulating water in cultivated fields. This model considered both changes in climate parameters and historical data and also imposed a threshold for data collection to save sensor energy. In [28], a cyber-physical intelligent agent was created for irrigation scheduling, which comprised perception, actuation, reasoning, and control systems. The heuristic was implemented in the reasoning system using crop modeling. The reasoning system forecasted the irrigation schedules with the highest water efficiency. In [29], an intelligent agriculture management system was developed to increase crop productivity and agricultural advantages by utilizing automation and the IoT. This system improved output and energy efficiency, reduced running expenses, and allowed remote control of the equipment.

The objectives of this study are:

- Minimize manual intervention by the farmers
- Prevent excess water loss
- Minimize power consumption
- Reduce production costs

II. EXPERIMENTAL SETUP

In the experimental setup shown in Figure 1, the Arduino UNO, sensors, and pump are all powered by a battery that is charged by a solar panel. A relay module is used to switch between the DC water pump connections. The microcontroller code allows the switching circuit to be signaled and the sensing device to be operated. The sensing unit's soil moisture sensor was used to gauge the soil moisture content and relay the data to the microcontroller for processing. Table I shows the detailed specifications for the components used.

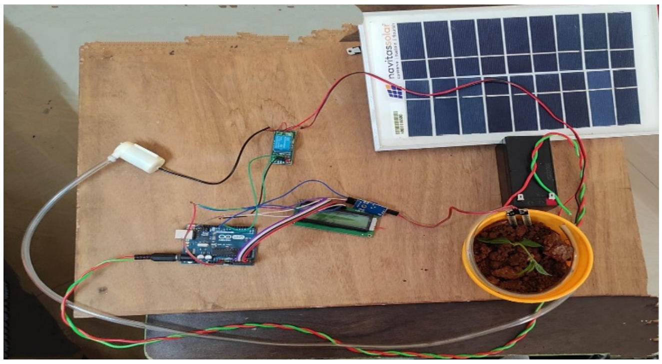

Fig. 1. Image of the solar-powered automated irrigation system setup using Arduino and moisture sensors.

TABLE I. COMPONENTS USED IN THE SOLAR-BASED AUTOMATIC IRRIGATION SYSTEM

Components	Specifications	Models	Units
Arduino microcontroller	5 V	ATmega328	1
Soil sensor	-	LM393	1
Moisture sensor module	-	LM393	1
DC Water Pump	5 V	TekBud	1
Single Relay Module	5 V	JQC-3FC	1
Solar Panel	5 W, 9 V	-	1
Voltage Regulator	-	LM7805	1
Rechargeable Battery	9 V – 12 V	Lead Acid	1
LCD Module	16 × 2	-	1

In this system, a battery powers the automatic irrigation system, which is charged using solar power. The system automatically irrigates the soil to maintain the ideal moisture levels using soil moisture sensors. The Arduino IDE was used, which is an open-source tool to write, build, and upload code to almost any Arduino module.

III. RESULTS AND DISCUSSIONS

The irrigation system begins to operate anytime the value of soil moisture falls below the threshold level. The LCD shows the soil moisture levels and a message notifying the user of the system's current state, such as whether it is ON or OFF.

A. Software Simulation

As shown in Figure 3, the motor will turn off and the indicator light will turn on if there is high moisture in the soil.

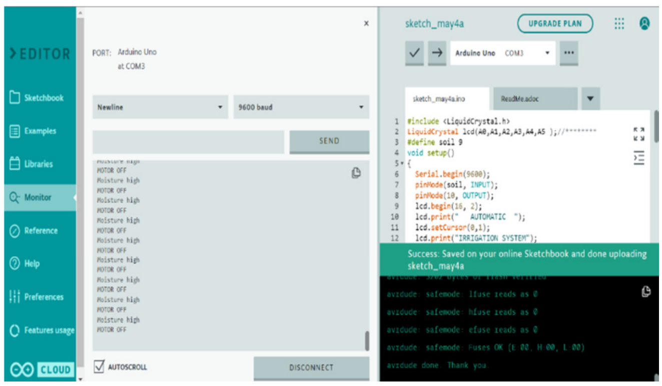

Fig. 2. A snapshot taken during the software run (part 1).

Figure 4 shows that an adequate amount of water is pumped up anytime the soil moisture sensor detects low moisture values.

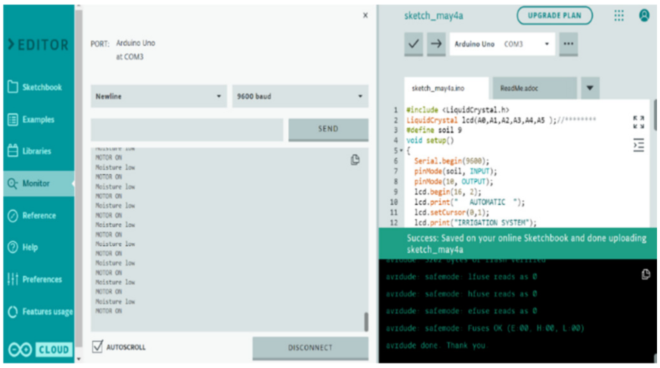

Fig. 3. A snapshot was taken during the software run (part 2).

B. Experimental Results

Table II shows the states of the pump. Different soil conditions were used to examine in which condition the motor will be ON/OFF. When the soil is wet, the relay circuit is open, and the water pump remains OFF. When the soil is dry, the water pump turns ON.

TABLE II. WATER PUMP CONDITION (ON/OFF) FOR DIFFERENT SOIL CONDITIONS USED

Soil condition	Relay triggering mode	Water pump operation
Excess Wet	Open	OFF
Optimally Wet	Open	OFF
Optimally Dry	Closed	ON
Dry	Closed	ON

Table III shows that the time required to irrigate the clay soil is more than sandy and loamy soil at 100% dryness.

TABLE III. IRRIGATION TIME REQUIRED FOR 100 % DRY SOIL FOR DIFFERENT SOIL TYPES USED

Soil Type	Irrigation time (s)
Sandy	5
Loamy	9
Clay	10

Table IV shows that the time required to irrigate clay soil is more than sandy soil at 50% dryness, and the time for irrigation is very low for sandy soil.

TABLE IV. IRRIGATION TIME REQUIRED FOR 50 % DRY SOIL FOR DIFFERENT SOIL TYPES

Soil Type	Irrigation time (s)
Sandy	1
Loamy	2
Clay	3

IV. CONCLUSION

This study demonstrated the development and implementation of a solar-powered automated irrigation system using Arduino and soil moisture sensors, specifically tailored to the conditions in Pune, India. Experimental results validate the system's ability to optimize water usage by supplying irrigation only when soil moisture falls below a threshold, ensuring water conservation and efficient energy utilization through solar power.

- The key novelty of this work lies in its integration of low-cost, locally available hardware components (Arduino Uno, soil moisture sensors, and solar panels) into a fully automated off-grid irrigation system.
- Unlike previous studies that focus on automation or solar power independently, this work combines both in a field-tested prototype, demonstrating practical viability and energy independence in semi-urban and rural settings.
- The system's performance was validated under real environmental conditions in Pune, adding practical insights that many simulations or lab-based studies lack.
- Compared to earlier works, this research offers improved affordability, easier deployment, and a modular design that can be adapted to various types of crops and soils. This study bridges the gap between concept and application, particularly for small to medium-sized farms facing energy and water resource constraints.
- This solution can be particularly valuable for farmers and gardeners who cannot dedicate time to manual irrigation. The system's ability to deliver precise amounts of water based on real-time soil conditions leads to substantial water savings. In areas prone to water scarcity, such as parts of India, this system can play a critical role in sustainable agricultural practices.

REFERENCES

[1] A. Oudrane, B. Aour, B. Zeghmati, X. Chesneau, and H. Massaoud, "Study and Simulation of the Density of the Incident Solar Flux on the Walls of a Building in Adrar, Algeria," *Engineering, Technology & Applied Science Research*, vol. 7, no. 5, pp. 1940–1945, Oct. 2017, https://doi.org/10.48084/etasr.1337.

[2] A. B. Kanase-Patil, A. P. Kaldate, S. D. Lokhande, H. Panchal, M. Suresh, and V. Priya, "A review of artificial intelligence-based optimization techniques for the sizing of integrated renewable energy systems in smart cities," *Environmental Technology Reviews*, vol. 9, no. 1, pp. 111–136, Jan. 2020, https://doi.org/10.1080/21622515.2020.1836035.

[3] A. Sohani, S. Ricart, H. Omidinasab, A. Sadooghi, H. Yagli, and H. Panchal, "Agriculture risks of pollutants in water and their benefits after purification," in *Sustainable Materials for Sensing and Remediation of Noxious Pollutants*, I. Tyagi, J. Goscianska, M. H. Dehghani, and R. R. Karri, Eds. Elsevier, 2022, pp. 39–46.

[4] S. J. Suji Prasad *et al.*, "An efficient LoRa-based smart agriculture management and monitoring system using wireless sensor networks," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 5447–5450, Dec. 2022, https://doi.org/10.1080/01430750.2021.1953591.

[5] B. Khan, A. A. Mir, N. S. Almutairi, and K. W. Goh, "Transactive IoT : Merging Transactions and Connectivity," in *IoT for Smart Grid*, 1st ed., R. Zahira, P. Sivaraman, C. Sharmeela, and S. Padmanaban, Eds. Wiley, 2025, pp. 63–85.

[6] S. S. Chandel, M. Nagaraju Naik, and R. Chandel, "Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies," *Renewable and Sustainable Energy Reviews*, vol. 49, pp. 1084–1099, Sep. 2015, https://doi.org/10.1016/j.rser.2015.04.083.

[7] V. C. Sontake and V. R. Kalamkar, "Solar photovoltaic water pumping system - A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1038–1067, Jun. 2016, https://doi.org/10.1016/j.rser.2016.01.021.

[8] D. H. Muhsen, T. Khatib, and F. Nagi, "A review of photovoltaic water pumping system designing methods, control strategies and field performance," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 70–86, Feb. 2017, https://doi.org/10.1016/j.rser.2016.09.129.

[9] R. Kumar, A. Kumar, M. K. Gupta, J. Yadav, and A. Jain, "Solar tree-based water pumping for assured irrigation in sustainable Indian agriculture environment," *Sustainable Production and Consumption*, vol. 33, pp. 15–27, Sep. 2022, https://doi.org/10.1016/j.spc.2022.06.013.

[10] A. R. Al-Ali, A. Al Nabulsi, S. Mukhopadhyay, M. S. Awal, S. Fernandes, and K. Ailabouni, "IoT-solar energy powered smart farm irrigation system," *Journal of Electronic Science and Technology*, vol. 17, no. 4, Dec. 2019, Art. no. 100017, https://doi.org/10.1016/j.jnlest.2020.100017.

[11] N. Wang and J. Liu, "The Research of Intelligent Irrigation Control System of Rice in Cold Region," *International Journal of Smart Home*, vol. 9, no. 9, pp. 129–138, Sep. 2015.

[12] S. Agarwal and N. Agarwal, "An algorithm based low cost automated system for irrigation with soil moisture sensor," in *2017 International Conference on Computer Communication and Informatics (ICCCI)*, Coimbatore, India, Jan. 2017, pp. 1–5, https://doi.org/10.1109/ICCCI.2017.8117741.

[13] J. Gutiérrez, J. F. Villa-Medina, A. Nieto-Garibay, and M. Á. Porta-Gándara, "Automated Irrigation System Using a Wireless Sensor Network and GPRS Module," *IEEE Transactions on Instrumentation and Measurement*, vol. 63, no. 1, pp. 166–176, Jan. 2014, https://doi.org/10.1109/TIM.2013.2276487.

[14] A. R. Al-Ali, A. Al Nabulsi, S. Mukhopadhyay, M. S. Awal, S. Fernandes, and K. Ailabouni, "IoT-solar energy powered smart farm irrigation system," *Journal of Electronic Science and Technology*, vol. 17, no. 4, Dec. 2019, Art. no. 100017, https://doi.org/10.1016/j.jnlest.2020.100017.

[15] N. Sudharshan, A. K. Karthik, J. S. Kiran, and S. Geetha, "Renewable Energy Based Smart Irrigation System," *Procedia Computer Science*, vol. 165, pp. 615–623, Jan. 2019, https://doi.org/10.1016/j.procs.2020.01.055.

[16] M. Pramanik *et al.*, "Automation of soil moisture sensor-based basin irrigation system," *Smart Agricultural Technology*, vol. 2, Dec. 2022, Art. no. 100032, https://doi.org/10.1016/j.atech.2021.100032.

[17] N. Lefore, A. Closas, and P. Schmitter, "Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture," *Energy Policy*, vol. 154, Jul. 2021, Art. no. 112313, https://doi.org/10.1016/j.enpol.2021.112313.

[18] B. Van Campen, D. Guidi, and G. Best, *Solar photovoltaics for sustainable agriculture and rural development*. Food and Agriculture Organization of the United Nations (FAO), 2000.

[19] A. R. Al-Ali, S. Rehman, S. Al-Agili, M. H. Al-Omari, and M. Al-Fayezi, "Usage of photovoltaics in an automated irrigation system," *Renewable Energy*, vol. 23, no. 1, pp. 17–26, May 2001, https://doi.org/10.1016/S0960-1481(00)00110-5.

[20] A. Shufian, Md. R. Haider, and Md. Hasibuzzaman, "Results of a simulation to propose an automated irrigation & monitoring system in crop production using fast charging & solar charge controller," *Cleaner Engineering and Technology*, vol. 4, Oct. 2021, Art. no. 100165, https://doi.org/10.1016/j.clet.2021.100165.

[21] O. Deveci, M. Onkol, H. O. Unver, and Z. Ozturk, "Design and development of a low-cost solar powered drip irrigation system using Systems Modeling Language," *Journal of Cleaner Production*, vol. 102, pp. 529–544, Sep. 2015, https://doi.org/10.1016/j.jclepro.2015.04.124.

[22] S. K. Luthra, M. J. Kaledonkar, O. P. Singh, and N. K. Tyagi, "Design and development of an auto irrigation system," *Agricultural Water Management*, vol. 33, no. 2, pp. 169–181, Jun. 1997, https://doi.org/10.1016/S0378-3774(96)01292-9.

[23] J. Rana, M. Kamruzzaman, M. Hosain Oliver, and K. Akhi, "Financial and factors demand analysis of solar powered irrigation system in *Boro* rice production: A case study in Meherpur district of Bangladesh," *Renewable Energy*, vol. 167, pp. 433–439, Apr. 2021, https://doi.org/10.1016/j.renene.2020.11.100.

[24] B. Li, M. K. Shukla, and T. Du, "Combined environmental stresses induced by drip irrigation positively affect most solar greenhouse grown tomato fruit quality," *Scientia Horticulturae*, vol. 288, Oct. 2021, Art. no. 110334, https://doi.org/10.1016/j.scienta.2021.110334.

[25] A. Closas and E. Rap, "Solar-based groundwater pumping for irrigation: Sustainability, policies, and limitations," *Energy Policy*, vol. 104, pp. 33–37, May 2017, https://doi.org/10.1016/j.enpol.2017.01.035.

[26] S. Biswas, L. K. Sharma, R. Ranjan, S. Saha, A. Chakraborty, and J. S. Banerjee, "Smart farming and water saving-based intelligent irrigation system implementation using the Internet of Things," in *Recent Trends in Computational Intelligence Enabled Research*, S. Bhattacharyya, P. Dutta, D. Samanta, A. Mukherjee, and I. Pan, Eds. Academic Press, 2021, pp. 339–354.

[27] S. A. Nikolidakis, D. Kandris, D. D. Vergados, and C. Douligeris, "Energy efficient automated control of irrigation in agriculture by using wireless sensor networks," *Computers and Electronics in Agriculture*, vol. 113, pp. 154–163, Apr. 2015, https://doi.org/10.1016/j.compag.2015.02.004.

[28] A. F. Jimenez, P. F. Cardenas, F. Jimenez, A. Ruiz-Canales, and A. López, "A cyber-physical intelligent agent for irrigation scheduling in horticultural crops," *Computers and Electronics in Agriculture*, vol. 178, Nov. 2020, Art. no. 105777, https://doi.org/10.1016/j.compag.2020.105777.

[29] B. P. Sangeetha, N. Kumar, A. P. Ambalgi, S. L. A. Haleem, K. Thilagam, and P. Vijayakumar, "IOT based smart irrigation management system for environmental sustainability in India," *Sustainable Energy Technologies and Assessments*, vol. 52, Aug. 2022, Art. no. 101973, https://doi.org/10.1016/j.seta.2022.101973.