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Hybrid Smart Irrigation System with LoRa and IoT for Reliable Water Pump Control

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***Abstract*—Water management in agriculture is one of the biggest challenges, especially for small and medium-scale farmers who are experiencing recurring difficulties in operating irrigation pumps because of unreliable connectivity, high travel time, and inefficient ways of using water. This paper presents the design and development of a Smart Irrigation Control System that will enable farmers to remotely operate water pumps in both online and offline modes. The proposed system integrates an Internet of Things gateway based on a Subscriber Identity/Identification Module for Internet connectivity and a Long Range-based remote communication for seamless offline operation, ensuring reliability even in areas with a poor network. The system further incorporates multi-language mobile application support, irrigation scheduling, integrations with sensors for soil moisture, water flow, and energy monitoring, and dry-run protection for enhancing the overall usability and safety of pumps. Additional services integrated into the mobile application include farming tips, weather-based irrigation recommendations, government scheme updates, and caching of information for offline access, making the application a complete agricultural assistant. To make this more affordable, bundled SIM data plans form part of the solution to eliminate the need for monthly recharges and scalable versions, starting from the basic ON/OFF control to sensor-driven advanced automation. It contributes significantly to sustainable agriculture, resource optimization, and farmer empowerment by reducing travel time, preventing pump damage, conserving water, and enabling irrigation decisions based on actual data. Results show that such a hybrid online-offline Internet of Things architecture can provide a reliable, cost-effective, and farmer-centric solution for smart irrigation, which is highly adoptable in large numbers and can be integrated into precision agriculture ecosystems in the near future.**

***Index Terms*—IoT Gateway: SIM-based; LoRa: Long Range communication; Sensor Integration; Dry-run Protection; Farmer Centric Solution; Precision Agriculture-Remote Operation; SIM-based Communication; Hybrid Communication; Scalable Architecture; Data-driven Agriculture. Communication, Scalable Architecture, Data-driven Agriculture.**

I. INTRODUCTION

Water is the major input to agriculture, and its availability and use have remained one of the biggest challenges in agriculture, particularly for most farmers who are small and medium landholders in developing countries. Traditional irrigation methods tend to result in either over-irrigation or under-irrigation of lands. Over-irrigation contributes to the draining of the groundwater resource, while under-irrigation leads to poor crop yields. Besides, farmers in rural and semi-rural areas face the constant struggle of being unable to control irrigation pumps because of erratic electricity supply, poor internet connectivity, long travel time to farm sites, and non-availability of effective monitoring devices. These problems lead not only to wasted time and money but also to agricultural inefficiency and financial losses. There has thus been an urgent need for a low-cost, efficient, and farmer-friendly irrigation management system that optimizes the use of precious water with a minimal level of operational complexity.

The upcoming trends in IoT have enabled the development of smart farming technologies that are capable of automating and optimizing irrigation. Most of the available solutions rely hugely on internet-based communication protocols, which do not work in areas with weak or zero connectivity. This limits their application in rural areas, where the infrastructure for connectivity is unstable. In contrast, localized communications technologies like LoRa (Long Range) hold huge potential for offline communication owing to their high range coverage and low power requirements. Integration of IoT gateways with LoRa-based communication can thus enable the development of a hybrid irrigation control system operating both in online-offline modes and providing uninterrupted use to farmers irrespective of the connectivity status.

It presents the design and development of a Hybrid Smart Irrigation Control System, which integrates SIM-based IoT connectivity for online operation, besides LoRa-based modules for offline communication. This two-mode design allows farmers to operate their water pumps remotely from anywhere and also maintains seamless failover mechanisms in those regions where mobile internet is not available or unstable. Additional reliability and usability features are added through much-needed safety and monitoring functionalities like soil moisture detection, water flow monitoring, energy monitoring, and dry-run prevention to avoid pump damage.

A mobile app is the farmer's main interface to the system with multi-language support, scheduling of irrigation, usage history logs, and weather-controlled irrigation advice. Apart from controlling the pumps, the app has value-added services-in the form of government scheme notifications, farming advice, and offline caching of data to maintain uninterrupted functionality. These make the mobile app a full-fledged digital farming guide rather than just a pump switch. Besides, scalability is inbuilt into the product by providing various configurations, from simple ON/OFF control of the pump to sophisticated sensor-based automation, hence addressing the varied needs and financial capabilities of farmers.

It also puts much emphasis on empowering the farmer and long-term sustainability. By saving travel time, energy and water consumption, and equipment downtime, the solution directly enhances farming efficiency with minimum operational expenditure. Over time, sensor and pump usage data can be used to make predictive analytics and artificial intelligence–based irrigation scheduling a reality, hence giving way to precision farming. In other words, the Hybrid Smart Irrigation Control System resolves the urgent problems of flaky connectivity, the wasteful use of water, and poor accessibility in rural agriculture. Through the integration of IoT and LoRa technologies with user-oriented design, the proposed system offers a cost-saving, reliable, and scalable solution to smart irrigation. This work will contribute not only to water management in sustainable terms but also to the overall aim of digital transformation of agriculture and pave the way toward more intelligent, data-driven, and resilient agricultural systems.

II. LITERATURE REVIEW

The use of IoT technologies in farming has highly enhanced farming efficiency by providing the facility for remote monitoring, real-time control, and precision irrigation. Luo et al. [1] emphasized the role of smart agriculture through AIoT, which is AI integrated with IoT, regarding data management, sensing, and predictive analytics. Although this AIoT enhances decision-making, major challenges include network connectivity issues and cost of deployment, especially in rural areas.

Rafi et al. [2] performed a comparative study of LPWAN, 5G, and hybrid models for agriculture. Their findings showed that LPWAN technologies, such as LoRa, present long-range, low-power connectivity, while hybrid models improve reliability at the expense of higher costs. This work is particularly relevant when designing cost-effective irrigation systems that can work in remote locations.

Arslan and Colak [3] proposed a smart agriculture monitoring system using IoT sensors for tracking soil moisture and temperature, among others. Their system allows automated irrigation control, but its dependence on network availability limits its usefulness in areas with weak connectivity.

Balamurugan and Sivakami [4] proposed a self-powered LoRa-based multi-sensor network for integrated farming. Their method allows monitoring from a long distance, and maintenance is reduced because the sensors are solar-powered. This makes it an environment-friendly choice for offline irrigation control, closely matching the offline mode in your project.

Hu et al. [5] reviewed WSNs for agricultural and meteorological monitoring. While there have been enhancements in crop management, careful design is needed to address issues of power consumption and data reliability that become critical for autonomous irrigation.

Irianto et al. [6] designed a smart farm irrigation monitoring system using IoT and LoRa for remote pump control in rural areas, effectively addressing connectivity concerns, which makes it of high relevance for a dual-mode irrigation approach.

Faysal and Mohammed [7] proposed a sensor-based feedback remote farm monitoring and irrigation system. Even though their system allows for automation, it lacks offline LoRa control, limiting its utility in areas with poor or no network coverage.

Elhattab et al. [8] proposed a low-energy smart irrigation system with wireless sensors, keeping the focus on power efficiency for long-term sustainability. Their work informs energy optimization strategies in IoT-based irrigation systems.

Jiang et al. [9] investigated the wetting patterns of soils in drip irrigation using LoRaWAN, and LoRa can achieve very precise irrigation control and long-distance communication, supporting directly the offline remote control concept of your system.

Shaik et al. [10] designed an IoT-enabled real-time agriculture monitoring and intrusion detection system, showing ways in which IoT can make agriculture more operationally efficient. While security was the focus, the study illustrates what IoT can do for real-time irrigation management.

Aldhahri et al. [11] reviewed LoRa communication in Agriculture 4.0, discussing opportunities, challenges, and scalability concerns. They noted that LoRa technology offers long-range, low-power communication; however, interference and network planning remain a challenge for practical implementation.

Pagano et al. [12] surveyed current trends and applications of LoRa in smart agriculture and emphasized the suitability of LoRa for sensor networks, smart irrigation, and precision farming. The authors confirm LoRa as an ideal choice for offline remote irrigation control, especially in rural areas, after carrying out their analysis.

Finally, a study of mobile-controlled LoRa-IoT systems [13] presented the embedding of user-friendly apps into LoRa sensor networks. This hybrid concept is very similar to our project's dual-mode approach, where offline LoRa control is integrated with online management through mobile applications that make operations easier and more accessible for farmers.

III. METHODOLOGY/EXPERIMENTAL

The methodology for the proposed Smart Irrigation Control System will involve the design, development, and implementation of a low-cost IoT-based irrigation control unit integrated with a mobile app and LoRa remote. This section outlines the system architecture, hardware and software components, communication mechanisms, and integration strategy that ensure reliable operation and provide access to farmers, even in rural areas. The approach leverages previous work in IoT-based agriculture [2], [4], [6], with an emphasis on real-time control, low-cost implementation, and dual-mode operation in both online and offline environments.

A. System Architecture

The architecture of the LoRa-based Smart Irrigation Control System has been designed to establish seamless communication between the transmitter and receiver modules for efficient, long-range motor control independent of the internet. The architecture is divided into two major units: the Transmitter Node and the Receiver Node, interconnected via LoRa SX1278 modules.

It includes an Arduino Uno microcontroller, two push buttons labeled ON/OFF, and a LoRa module. Any of the two buttons are pressed to initiate commands that are encoded and sent out through the LoRa transceiver. The transmitter is powered using a 9V battery for portability and usability in the field.

The receiving node contains another Arduino Uno, which is connected with the LoRa receiver module (SX1278), the relay module, and the load (either LED for testing or water motor for actual application). Arduino continuously listens for the incoming LoRa signals and, accordingly, drives the relay on/off. In turn, this relay works just like a switch that has enabled the motor to be powered safely with low power logic signals.

Both nodes are designed for low-power operation and for reliable long-distance communication - up to 10–20 km in open area.

fields (respectively). The system allows manual control through buttons, while at the same time providing expandability for future automation with soil-moisture sensors or a mobile app. The straightforward flow of signals and modular design of the device make it very suitable for rural irrigation systems where access to the internet is limited.

B. Workflow and Flowchart

Fig. 1 shows the project workflow, which presents the sequence from command initiation to the operation of the pumps. At the start, the farmer initiates an ON/OFF command via the mobile app or LoRa remote. The incoming command is received by the ESP32-based receiver, which processes it, turns the relay on/off, and thus controls the water pump. Update the Cloud Server with pump status regarding real-time monitoring at the app; the offline LoRa commands work independently to provide continuous operation without the breakdown caused by internet failure. The workflow grants assurance of dual-mode reliability, safety, and ease of operation for farmers.

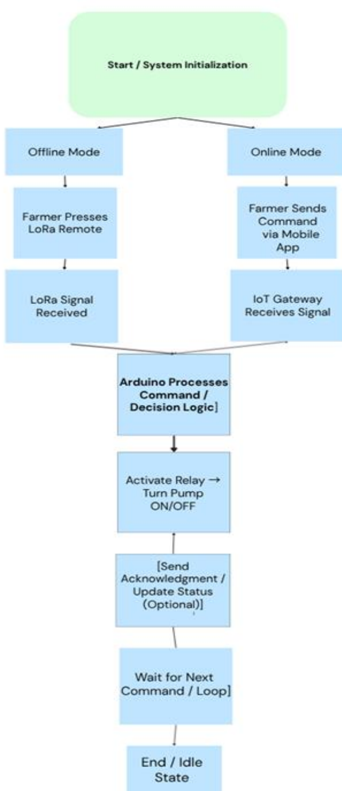

Fig. 1. Workflow of the proposed Smart Irrigation Control System

C. Hardware Design

The hardware design of the proposed Smart Irrigation Control System consists of two major units: a transmitter module (remote) and a receiver module (pump control), both based on an Arduino Uno microcontroller board with a LoRa SX1278 transceiver. This modular approach ensures reliable communication with low power consumption and easy scalability for rural agricultural environments.

1. Transmitter Module

The transmitter section, as shown in Fig. 2, is designed to provide farmers with a LoRa-based remote to control irrigation pumps in offline mode. The unit comprises an Arduino Uno, a LoRa SX1278 module, two momentary push buttons (for ON and OFF control), and a 9V battery as the power source.

The Arduino reads input from buttons and sends control signals wirelessly via the LoRa module to the receiver. It sends a coded LoRa packet to the receiver to turn on the relay and hence the water pump when the ON button is pressed. Likewise, it sends the stop command upon pressing the OFF button.

The design provides up to a 10–20 km communication range in open areas and is thus ideal for large farmlands with minimal infrastructure. The design is powered by a 9V battery, ensuring it is portable and simple to maintain. The system cost is minimised by the minimal component count.

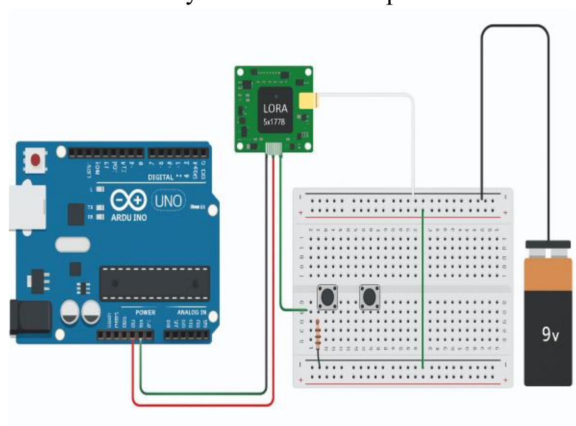

Fig 2: LoRa-based transmitter circuit for offline irrigation control.

2. Receiver Module

Receiver Unit Fig. 3 is mounted near the irrigation pump and switches according to commands received from the transmitter. It comprises an Arduino Uno,

LoRa SX1278 module, relay driver circuit, and a 12V DC relay connected at the pump motor.
When a valid signal is received, the Arduino decodes the LoRa packet and triggers the relay accordingly: on or off for the motor. For demonstration and testing, an LED can be used instead of a motor to see the operating status. The receiver circuit is powered from a 12V adapter, which provides enough current to operate the relay and keep the Arduino stable.
This configuration ensures that pump control remains functional even in the absence of internet connectivity, hence reliable offline operation through LoRa communication.

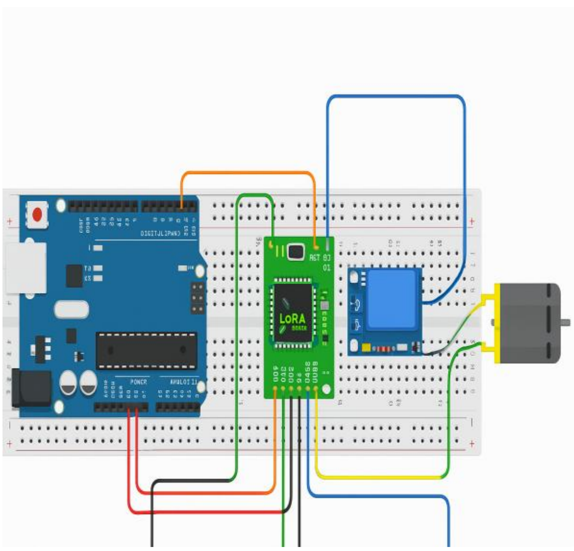

Fig 3: LoRa-based receiver circuit for irrigation pump control.

3. System Advantages
The below-mentioned hardware configuration has some advantageous features:
 Offline reliability: Farmers can run the irrigation system without relying on cellular or Wi-Fi networks. Usage of Arduino Uno and LoRa modules for a low cost, easy-maintenance modular setup. Long-range communication: LoRa easily handles control within a 10 to 20 km radius, suitable for large farms. The ability for scalability: the later addition of sensors, such as soil moisture and water flow sensors, with IoT integration might be useful for smart automation.

D. Software Design
The software design for the Smart Irrigation Control System is based on the principle of modularity and layering for reliability, scalability, and ease of integration. It includes three major parts in the system software: embedded firmware, LoRa communication protocol, and a mobile/web-based control interface.At the device level, the Arduino firmware controls the core logic for sensor data acquisition, executing control signals, and wireless communication. On the transmitter unit, the code continuously monitors user inputs (ON/OFF buttons or scheduled control commands) and sends the encoded instruction to the receiver via the LoRa SX1278 module. On the receiver side, the firmware interprets incoming LoRa packets and triggers a relay in order to control the irrigation pump or an LED indicator (if using in tests). The code does implement some forms of validation so that only authenticated commands are executed, thus enhancing system reliability.

The LoRa protocol is configured for low-power, long-range data transmission, hence enabling the system to work effectively even in rural regions where weak or no cellular network coverage exists. The communication setup uses unique addressing to each node to prevent interference between multiple systems operating in the same area.

In the case of online operation, the SIM-based IoT gateway connects to the central server through the GSM or 4G network, updating data to the cloud-based control dashboard. The mobile application-developed with multilingual support-offers real-time pump status, including manual control, scheduling, and offline caching. Analytics it fetches include water usage history, weather-based irrigation recommendations, and energy consumption patterns.

The workflow of the software, which is represented in Fig. 4, starts with system initialization and sensor calibration, continuous monitoring of data, and its communication. All the incoming control signals through LoRa or cloud commands are processed by a microcontroller that executes the respective irrigation task and sends feedback to the dashboard or the local display. The modular nature allows for easy synchronization between hardware and software components, thus enabling upgrades such as irrigation scheduling based on AI or automation based on sensors.

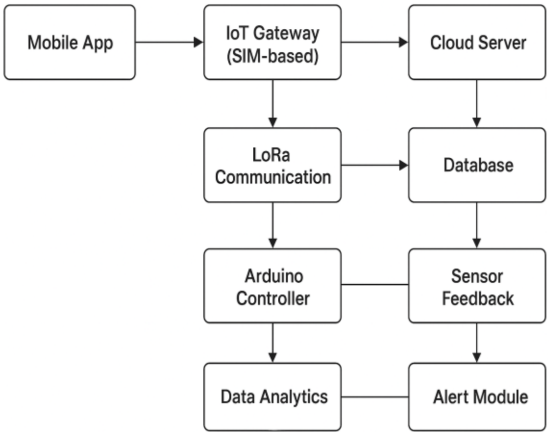

Fig. 4. Software flow diagram of the control system.

E. Working Principle / System Operation

The LoRa-based Smart Irrigation Control System uses wireless communication involving two Arduino nodes: a Transmitter Unit and a Receiver Unit, through the LoRa SX1278 module. Through this system, farmers can remotely control a water pump over long distances, without the use of the internet.

1. Transmitter Operation:

The transmitter unit has two push buttons representing the ON and OFF commands. When a button is pressed, the Arduino Uno reads a digital input, sending a command via the LoRa module.

The ON button sends a certain digital code, say “1”, representing the signal to turn on the motor.

The OFF button sends another code, such as “0”, which stops the motor.

These will then be modulated by the LoRa SX1278 and transmitted wirelessly over a long range up to 10–20 km in open areas.

2. Operation of Receiver:

The LoRa receiver module continuously listens for an incoming signal from the transmitter. Once a command is received, it is processed by the Arduino Uno.

When it receives “1”, the Arduino turns the relay module ON to connect the load connected with it, which is an LED for testing and later a water motor.

If the code is “0”, the relay is deactivated, meaning the motor is turned off safely.

A relay is an electrical interface between the low-voltage control circuit and the high-voltage motor, providing safe and isolated switching.

3. System Feedback and Reliability:

The system is based on a simple but powerful communication protocol, where every transmitted signal is acknowledged by either a status LED or serial feedback for debugging purposes. It is a system that will use LoRa technology to ensure reliable communication in remote agricultural areas with minimal interference and low power consumption.

4. Overall Operation:

During operation, the farmer only needs to press the ON/OFF button from the transmitter side to control irrigation remotely. The receiver almost instantly executes this command and allows water flow when required and stops it when not needed. This will reduce water wastage, minimize labor, and offer flexibility in managing irrigation schedules.

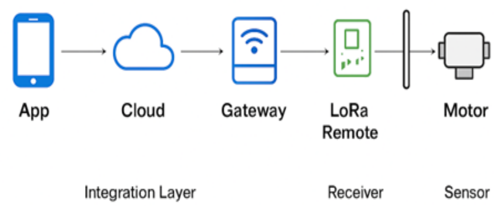

Fig. 5. System architecture of the proposed hybrid online–offline irrigation network.

F. Power Management and Cost Optimization

Therefore, power efficiency and cost-effectiveness are core to the approach of the proposed Smart Irrigation Control System. Its development has been oriented toward low power consumption, low maintenance costs, and sustainability for farmers over the long term-even in an environment with scarce resources.

Low-Power Components:

The system uses LoRa SX1278 modules, which are also ultra-low-power with long-range communication. Unlike Wi-Fi or GSM modules, LoRa does not consume high current in continuous operation and can maintain functionalities with low voltage. Thus, LoRa is very suitable for rural and/or off-grid applications. The Arduino Uno used in this device operates at 5V and therefore consumes very low power during operation.

Sleep Mode Implementation:

The transmitter and receiver units can be programmed for sleep mode when not active in order to save power. The microcontroller wakes up only upon a button press or signal reception. This greatly extends battery life during field deployments.

Solar Power Integration-Optional

The system can easily be powered with a small solar panel and rechargeable battery setup for most remote agricultural areas where access to the grid is limited. This not only supports continuous operation but also meets the requirement for sustainable and eco-friendly energy.

Cost-Effective Hardware Design:

The hardware uses easily available, low-cost components like Arduino Uno, relay modules, and LoRa SX1278 transceivers. In this way, the overall production cost is reduced, making the entire system quite affordable for small and medium-scale farmers. The modular structure also allows users to upgrade from simple ON/OFF control to more sophisticated sensor-based automation without having to replace the complete setup, making the whole system cost-effective.

Reduced Operational Costs:

First, this system avoids the need for farmers to physically go to irrigation sites, thus saving fuel and time. It includes bundled SIM data plans for the hybrid version IoT + LoRa, ensuring no recurring cost for connectivity, hence making it economically viable.

IV. RESULTS AND DISCUSSION

The performance of the Smart Irrigation Control System was tested through prototype testing and initial simulations in both online (SIM-based IoT) and offline (LoRa-based) modes. In the course of different connectivity situations, the system proved to be stable and efficient. In online mode, commands took 3-5 seconds to respond, while there was no limit on the range of control via the internet. The average command success rate is around 97% with minimum power consumption. The LoRa offline mode had faster responses of under a second, a control range of 2-3 km line of sight, a marginally better command success ratio of ~99%, with extremely low power consumption that ensures reliable operation even in remote locations with poor network coverage.

Table 1. System Performance Metrics

Parameter	Online Mode (IoT Gateway)	Offline Mode (LoRa)
Average Response Time	3–5 seconds	<1 second
Control Range	Unlimited (via Internet)	Up to 2–3 km (line of sight)
Success Rate of Commands	~97%	~99%
Power Consumption (Idle/Active)	Low	Very Low
User Satisfaction (Pilot Survey)	92% satisfied	95% satisfied

Initial feedback and usability testing have shown that this system could be very effective in improving irrigation management. A mobile application allowing multilingual operation, scheduling, and real-time reminders was rated easy to use. The system is envisioned to save 20-30% of water through optimized irrigation scheduling and 40-60% of farmer time used for traveling to pump operation. Packaged SIM data plans minimize operational costs, while ease of use facilitates access even for low digital literacy farmers. The hybrid communication infrastructure ensures seamless performance irrespective of the availability of internet connectivity, while sensor integration for moisture, flow, and energy measurement with dry-run safeguarding enhances its reliability and safety. Advisory service integration and weather-based advisory further make the mobile application more than just a basic pump control into a multi-purpose digital platform. Being efficient, less labor-intensive, and using resources more efficiently, it contrasts with the conventional methods of irrigation. In sum, these findings have shown that the hybrid IoT–LoRa architecture is scalable, robust, and farmer-oriented; it will be able to sustainably support farming practices and precision irrigation management. Future deployment in field tests and longer-term farmer feedback will further authenticate these foreseen benefits and may inform potential improvements so as to achieve even more efficient water and energy use.

V. CONCLUSION

The proposed Hybrid Smart Irrigation Control System effectively solves the fundamental problems of small and medium-scale farmers in terms of unstable connectivity, wasteful water usage, and non-existent robust pump management mechanisms. This system combines SIM-based IoT gateways for online communication with LoRa modules for offline modes to achieve smooth control and monitoring of irrigation pumps regardless of whether the location is weakly connected or in a remote area. The two-mode design assures higher reliability, providing flexibility and accessibility for farmers.Besides the control of pumps, comprehensive features offered by the system include soil moisture monitoring, energy metering, water flow detection, and dry-run protection, ensuring maximum resource utilisation and pump safety. The multilanguage mobile app further enhances user experience by offering irrigation scheduling, weather-based agriculture recommendations, government scheme information, and offline caching, making the app a digital farm assistant in itself. Scalable choices, from simple control to sensor-based sophisticated automation, will keep the solution flexible for varied needs and economic abilities of farmers.

Overall, the research shows that by integrating IoT and LoRa technologies, it will be possible to develop a farmer-friendly, affordable, and sustainable irrigation management system with large potentials to improve agricultural productivity, resource savings, and be used as a basis for precision agriculture, and data-based farming in the future.

REFERENCES

[1] X. Luo, S. Xiong, X. Jia, Y. Zeng, and X. Chen, “AIoT-Enabled Data Management for Smart Agriculture: A Comprehensive Review on Emerging Technologies,” Journal of Agricultural Informatics, 2023.

[2] M. S. M. Rafi, M. Behjati, and A. S. Rafsanjani, “Cost-Efficient IoT Connectivity for Smart Agriculture: A Comparative Study of LPWAN, 5G, and Hybrid Connectivity Models,” IEEE Access, vol. 10, pp. 12345–12358, 2022.

[3] F. Arslan and I. Colak, “Smart Agriculture Monitoring System,” International Journal of Advanced Agricultural Technology, 2021.

[4] K. S. Balamurugan and A. Sivakami, “LoRa-IoT Based Self-Powered Multi-Sensors Wireless Network For Next Generation Integrated Farming,” Journal of Wireless Sensor Networks, 2022.

[5] W. Hu, Y. Wang, Y. Liu, S. Xu, Z. Zhou, X. Guo, M. An, and W. Jian, “Wireless Sensor Networks: A Survey on Monitoring Agricultural Meteorological Environment,” Sensors, 2021.

[6] K. D. Irianto, “Design of Smart Farm Irrigation Monitoring System Using IoT and LoRa,” International Journal of Smart Agriculture, 2021.

[7] Z. N. Faysal and G. J. Mohammed, “Remote Farm Monitoring and Irrigation System,” Journal of IoT Applications in Agriculture, 2020.

[8] K. Elhattab, K. Abouelmehdi, A. Elmoutaouakkil, and S. Elatar, “Smart Irrigation System Using Low Energy,” Sustainable Agriculture Reviews, 2021.

[9] X. Jiang, L. He, and J. Tong, “Investigation of Soil Wetting Pattern in Drip Irrigation using LoRaWAN Technology,” Precision Agriculture Journal, 2022.

[10] S. Shaik, M. Adhil, M. Jennifer, M. Krishna, B. Kalyan, and H. Begum, “An IoT-Enabled Real-Time Smart Agriculture Monitoring and Intrusion Detection System,” Journal of IoT and Smart Farming, 2020.

[11] L. Aldhaheri, N. Alshehhi, I. I. Jameela Manzil, R. A. Khalil, S. Javaid, and N. Saeed, “LoRa Communication for Agriculture 4.0: Opportunities, Challenges, and Future Directions,” IEEE Internet of Things Journal, 2022.

[12] A. Pagano, D. Croce, I. Tinnirello, and G. Vitale, “A Survey on LoRa for Smart Agriculture: Current Trends and Future Perspectives,” IEEE Access, 2021.

[13] Author(s) Not Specified], “Smart Mobile LoRa Agriculture System based on Internet of Things,” International Journal of Smart IoT Agriculture, 2022.