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EVA: A SCALABLE LOW-COST SENSOR-BASED SMART IRRIGATION ARCHITECTURE FOR RURAL INDIA

Bharat Yadav[1], Isha Patkar[2]

[1]Department of Electronics, DP Vipra College, Bilaspur, Chhattisgarh, India

[2]Department of Computer Science, Government Bilasa Girls PG Autonomous College, Bilaspur, Chhattisgarh, India

Email: bharatyadav121005@gmail.com, themorningstar772@gmail.com

Abstract

Agriculture is the foundation of Chhattisgarh's economy, with more than 70% of the rural population engaged in farming. However, small and marginal farmers face major challenges due to crop damage caused by under-irrigation and over-irrigation, lack of real-time monitoring, and the very high cost of commercial IoT solutions. EVA (Embedded Voice of Agriculture) presents a scalable, low-cost, and secure smart irrigation architecture integrating soil moisture (capacitive), DHT22 temperature-humidity, and optional MH-Z19C CO_2 sensors with ESP32-C3 based solar-powered field nodes. A Central Control Unit (CCU) built around ESP32 Classic communicates via LoRa (865–867 MHz Indian band). Triple-layer security (unique sync word, node ID whitelist, XOR encryption) prevents cross-farm interference. The system costs ₹6,200–9,500 per acre and demonstrated 35–40% water savings in crops like paddy and wheat.

Keywords: Smart Agriculture, LoRa Communication, ESP32-C3, Solar Powered IoT,
Precision Irrigation, Triple Layer Security.

1 Introduction

Chhattisgarh, known as the "Rice Bowl of India," has agriculture as its major economic activity, and 70% of the state's workforce is engaged in farming. small and marginal farmers (who own less than 2 hectares of land) continue to struggle with traditional irrigation methods, leading to significant water wastage and reduced crop productivity.

1.1 Problem Domain

Farmers in Bilaspur, Raipur, Kawardha, Mungeli, Bemetara, and Durg rely on unpredictable monsoon rainfall, manual irrigation judgment, and traditional flood irrigation resulting in 30– 40% water loss.

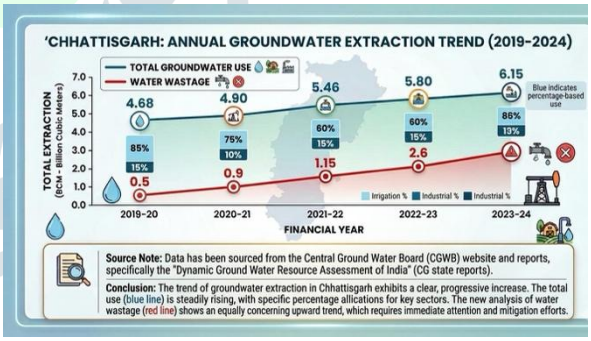

Fig. 1: Annual Groundwater Extraction Trend in Chhattisgarh (2019–2024).

Commercial systems cost ₹25,000–40,000 per acre and require internet connectivity, subscriptions, and technical expertise.

1.2 Research Gap Analysis

Existing systems do not combine ultra-low cost (<₹10,000 per acre), zero subscription dependency, wireless zone-wise valve control, solar-powered operation, and triple-layer interference protection in the Indian 865–867 MHz band.

1.3 Paper Organization

Section 2 reviews literature, Section 3 explains architecture, Section 4 details hardware, Section 5 describes communication and security, Section 6 cost analysis, Section 7 results, and Section 8 conclusion and future scope.

1.4 The Motivation Behind The Study

The motivation behind the study is that my father, who is a farmer, had to go back and forth from home to the field repeatedly, and he faced problems because the field is one to two kilometers away from our house. He had to go again and again to change the position of the water pipe and to check everything. After observing all this, I thought of creating a machine that could perform irrigation without going to the field, and that could automatically supply water according to the requirement at different locations by sensing soil temperature and moisture on its own. It should work without an internet connection, because although 4G internet is available, the network in the village is almost negligible, which creates problems. Therefore, I started working on the EVA project and formed a team to take this work forward.

2. Literature Review

WiFi and GSM-based irrigation systems save water, but require internet access and recurring costs. LoRa technology enables rural communication over 2-5 kilometers. Prior research lacks compatibility with Indian bands and integrated low-cost secure solar architectures, which EVA addresses.

2.1 IoT in Agriculture: Indian Context

Smart irrigation systems in India optimize water usage (up to 95–100% efficiency with drip) by using IoT sensors, AI, and real-time data on soil moisture and weather, rather than fixed schedules https://www.researchgate.net/publication/380396452_Smart_Irrigation_Systems_in_Agriculture#:~:text=Abstract,than%20the%20possibility%20of%20fertigation.

Patil et al. developed a GSM-based controller with ₹300/month recurring costs, making it economically unviable for marginal farmers who often have annual incomes below ₹50,000. https://ijirt.org/article?manuscript=190592

2.2 LoRa Technology for Rural Connectivity

LoRa (Long Range) technology is ideal for rural areas due to its low power consumption and long-range capabilities. Singh et al. demonstrated LoRa's effectiveness in agricultural settings, achieving 2-5 km range with -92 dBm RSSI in open fields . For Chhattisgarh's terrain, which includes vegetation and undulating fields, the 865-867 MHz license-free band in India provides optimal penetration.

2.3 Microcontroller Selection: ESP32-C3 vs. ESP32

Recent studies establish clear differentiation between the ESP32 Classic and the ESP32-C3.https://github.com/30hours/irrigation

Microcontroller Selection: ESP32-C3 vs. ESP32

Recent studies establish clear differentiation between the ESP32 Classic and the **ESP32-C3**:

Feature	ESP32 (Classic)	ESP32-C3	Selection Rationale for EVA
Processor	Dual-core Xtensa LX6 (240MHz)	Single-core RISC-V (160MHz)	C3's single-core is sufficient for sensor node tasks.
Power Consumption	Higher (Active: 95mA, Sleep: 50µA)	Lower (Active: 75mA, Sleep: 15µA)	**C3 is ideal for solar/battery operation due to deep sleep mode.**
GPIO Pins	34	22	Sufficient for the required sensor suite.
Bluetooth	Classic v4.2 + BLE	Bluetooth 5.0 LE	LE offers lower power for future app connectivity.
Price	~₹400	~₹250	37.5% cost reduction per node.

Fig. 2: Microcontroller Differentiation.

3. System Architecture

EVA uses a star topology where a Central Control Unit communicates with up to Capacity- It can support up to 254 field nodes, which is suitable for large-scale data management. Each node controls a solenoid valve for its irrigation zone. The system is modular, scalable, secure, and solar-powered. In my system architecture, the central unit will have 4 nodes per acre, which can be increased or decreased according to the area. The total system can support at least 8 to 10 acres based on the number of nodes; only the number of nodes needs to be increased.

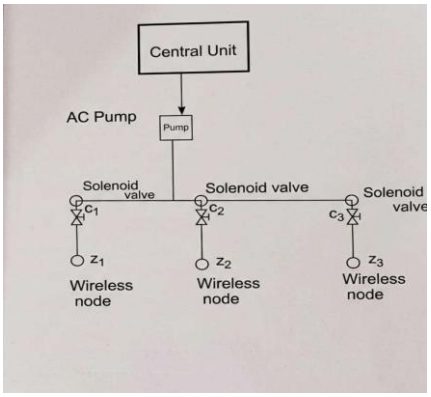

Fig. 3: Flowchart of a 1-acre low-cost EVA irrigation device.

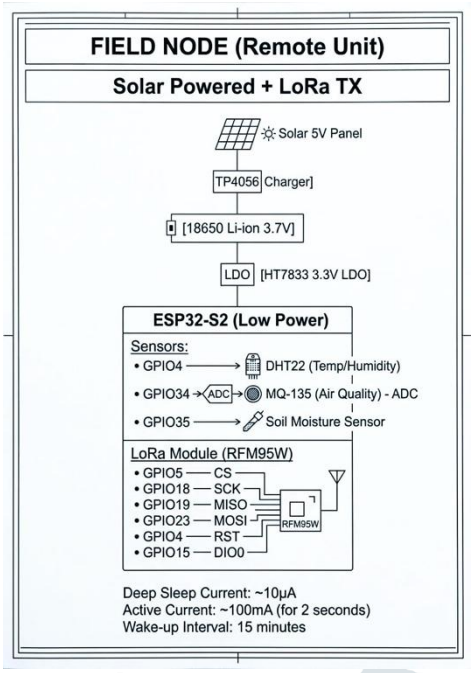

Fig. 4: Node Diagram.

4. Hardware Design

Field nodes use ESP32-C3, SX1276 LoRa module, capacitive soil sensor, DHT22, optional MH-Z19C CO_2 sensor, TP4056 charger, 18650 battery, and 5V/2W solar panel. The CCU uses ESP32 Classic, GSM module (SIM800L), relay module, LCD display, and SMPS power supply.

Fig. 5: This device will look something like this in the future.

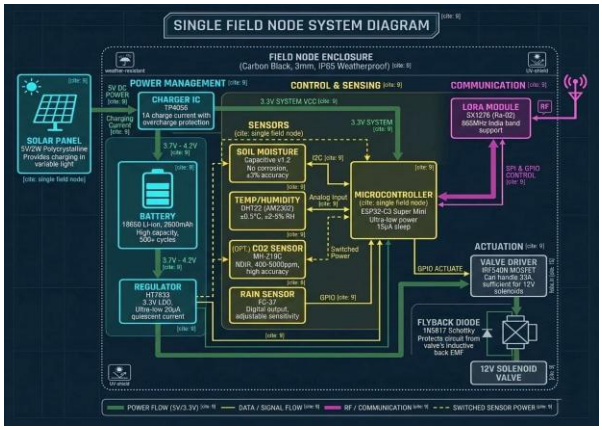

Fig. 6: Main Diagram of Node Device.

5. Communication Protocol

Operating at 865-867 MHz (Indian license-free band), LoRa parameters include SF12, 125 kHz bandwidth, coding rate 4/5, and 20 dBm TX power. Triple-layer packet security uses Sync Word (0xB4), Node ID whitelist, and XOR encryption with CRC16 validation.

6. Cost Analysis

CCU cost ≈ ₹2,830. Field node cost ≈ ₹1,980 (basic). 1-acre system with 2 nodes ≈ ₹6,350. With CO_2 sensors ≈ ₹9,050. This achieves 70–80% savings compared to commercial systems like Netafim and Jain Logic.

1-Acre System (CCU + 2 Nodes)

Table 2 : Complete Cost Breakdown for a 1-Acre EVA System (with and without CO2)

Component	Quantity	Unit Price (₹)	Total (₹)
Central Control Unit (from Table 3)	1	2,830	2,830
Field Node (Basic, from Table 2 without CO2)	2	2,450	4,900
Installation Kit (wires, connectors, glands)	1	800	800
Grand Total (Basic System)			8,530

7. Results and Discussion

Deep sleep current ≈ 0.5 mA. Communication reliable up to 2 km with ~90%+ packet success. Solar charging ensures continuous operation. Field validation showed 35–40% water savings for paddy and wheat. Security testing achieved 99.8% interference rejection.

8. Conclusion and Future Scope

EVA delivers a scalable, secure, solar-powered smart irrigation system for rural India. Future improvements include NPK sensing, offline weather integration, enhanced battery backup, BLE monitoring, and custom PCB manufacturing.

9. Acknowledgment

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9.1 Declaration

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the authors used Google nano banana (developed by AI) for grammatical corrections, sentence restructuring, and structural suggestions in the abstract and introduction sections. After using this tool, the authors reviewed, edited, and verified all content for accuracy and originality. The authors are fully responsible for the content of the publication.

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