AI-Driven Eco-Smart Irrigation System

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***Abstract*—Traditional irrigation systems often depend on manual operation and fixed watering schedules, which can lead to water wastage, increased labour requirements, and inefficient crop management. This paper presents an AI-Driven Eco-Smart Irrigation System that integrates Artificial Intelligence (AI), LoRa-based communication, and a custom mobile application to automate irrigation and improve water utilisation. The proposed system uses two ESP32 microcontrollers connected through LoRa for reliable long-range wireless communication. A raindrop sensor and two soil moisture sensors continuously monitor field conditions, while the receiver unit controls two solenoid valves and a water pump according to predefined soil moisture thresholds. The field unit is powered by a solar panel and rechargeable battery, enabling energy-efficient and off-grid operation. The Eco-Smart Irrigation mobile application provides real-time monitoring, remote irrigation control, manual override, and irrigation status updates. In addition, an AI-based recommendation module analyses soil conditions and provides suitable crop recommendations to support agricultural productivity. By combining automated sensing, wireless communication, renewable energy, and AI-based decision support, the proposed system reduces unnecessary water consumption and manual intervention while improving irrigation management. The system is designed for potential application in farms, nurseries, and home gardens, supporting efficient and sustainable agricultural practices.**

***Index Terms*—Artificial intelligence (AI), Eco-Smart irrigation application, ESP32, LoRa communication, Precision agriculture, Smart irrigation, Solar-powered system.**

I. INTRODUCTION

Agriculture plays a vital role in ensuring food security and supporting economic development. However, efficient water management remains a major challenge due to irregular rainfall, water scarcity, and the inefficient use of conventional irrigation practices [2]. Traditional irrigation systems often depend on manual operation and fixed watering schedules, which can result in unnecessary water consumption, increased labour requirements, and inconsistent irrigation [1]. These challenges create a need for intelligent irrigation solutions that can monitor field conditions and regulate water supply according to actual crop requirements [4].

Recent developments in the Internet of Things (IoT), wireless communication, renewable energy, and Artificial Intelligence have enabled the development of automated irrigation systems [6]. Sensor-based irrigation systems can continuously monitor parameters such as soil moisture and rainfall, while wireless communication technologies enable remote monitoring and control [9]. However, many existing systems have limitations such as dependence on short-range communication [11], limited remote-control capabilities, dependence on conventional power sources, or the absence of intelligent crop recommendations [17]. These limitations indicate a research gap in integrating long-range communication, renewable energy, automated irrigation, mobile-based monitoring, and AI-driven decision support within a single system [18].

To address these challenges, our paper presents an AI-Driven Eco-Smart Irrigation System that integrates sensor technology, ESP32 microcontrollers, LoRa communication, solar power, a mobile application, and an AI-based recommendation module. The proposed system uses two ESP32 microcontrollers connected through LoRa to establish reliable long-range communication between the field and receiver units [13]. A raindrop sensor and two soil moisture sensors continuously monitor field conditions. Based on predefined soil moisture thresholds, the receiver

unit automatically controls two solenoid valves and a water pump to regulate irrigation [7].

The proposed system is also designed to provide remote accessibility through the Eco-Smart Irrigation Application, which enables users to monitor soil moisture levels, control irrigation remotely, switch between automatic and manual modes, and view irrigation status in real time [16]. The field unit is powered using a solar panel and rechargeable battery, supporting energy-efficient and off-grid operation [12]. In addition, the AI-based recommendation module analyses soil conditions and provides suitable crop recommendations to assist users in making informed agricultural decisions [8].

The main objective of our work is to develop an integrated and sustainable irrigation solution that reduces unnecessary water consumption, minimises manual intervention, and improves irrigation management. The key contribution of the proposed system is the integration of automated sensor-based irrigation, LoRa-based long-range communication, solar-powered operation, mobile application control, and AI-based crop recommendations within a unified platform. The proposed system is intended for potential use in farms, nurseries, and home gardens, supporting efficient water utilisation and sustainable precision agriculture [5].

II. LITERATURE SURVEY

The study presents Smart Automated Irrigation System with Pest Control & IoT Monitoring proposes an IoT-based agricultural system using ESP32, soil moisture sensors, and IR sensors. It automatically controls a water pump according to soil moisture levels and detects pest movement using an IR sensor, activating a buzzer, LED, and ultrasonic repellent. The Blynk platform enables real-time monitoring and remote control through a smartphone. The system reduces water wastage, manual labour, and the use of chemical pesticides. The authors suggest adding weather sensors, solar power, and advanced pest detection methods to improve performance and support sustainable agriculture [1].

Smart irrigation systems use advanced technologies such as the Internet of Things (IoT), Wireless Sensor Networks (WSN), and solar energy to improve water management in agriculture. Soil moisture, temperature, and humidity sensors help monitor field conditions and control water supply efficiently. IoT technology allows farmers to monitor and operate irrigation systems remotely using smartphones and web applications. Wireless sensor networks enable communication between sensors and control devices, while solar-powered systems reduce electricity costs and dependence on conventional energy sources. These technologies help conserve water, reduce manual labour, and improve crop productivity. However, challenges such as installation costs, power availability, and communication reliability need to be addressed. Integrating these technologies can support efficient water utilisation and sustainable agricultural practices [6].

Smart farming systems use Arduino, sensors, solar energy, and wireless communication to improve agricultural efficiency. The system monitors soil moisture, water levels, temperature, and humidity to control irrigation and reduce water wastage. Solar panels provide clean energy, while ZigBee and GSM enable wireless communication and remote monitoring. Additional flame and gas sensors improve farm safety. This system reduces labour, energy consumption, and operating costs while improving crop productivity and promoting sustainable agriculture [11].

Smart irrigation systems using hybrid Artificial Intelligence and fog computing help predict irrigation requirements and improve water management in agriculture. The system collects environmental data such as temperature, humidity, and time using IoT devices and sensors. It combines Gradient Boosting, Random Forest, and Logistic Regression algorithms to predict when irrigation is required. Fog computing processes data closer to the source, reducing delay and enabling faster decisions, while cloud computing supports data storage and access. The proposed model achieved an accuracy of 97.78%, demonstrating reliable irrigation prediction. This approach helps conserve water, improve crop productivity, and support efficient and sustainable farming [18].

Smart irrigation systems using IoT and cloud computing help automate irrigation and improve water management in agriculture. The system uses an Arduino UNO, ESP-01 Wi-Fi module, soil moisture sensor, relay, and water pump to monitor soil moisture and control water supply automatically. When the soil moisture level falls below 20%, the pump is activated to irrigate cotton crops. The sensor data is sent to the

ThingSpeak cloud platform, allowing farmers to monitor soil conditions remotely. The system reduces water wastage, manual effort, and operational costs while supporting efficient irrigation and sustainable agriculture [4].

The AI-driven adaptive smart irrigation system uses IoT, machine learning, and cloud computing to improve water management in agriculture. Sensors collect real-time data on soil moisture, temperature, humidity, water levels, and weather conditions. A Support Vector Machine (SVM) classifier predicts irrigation requirements and automatically controls pumps and valves based on crop and environmental needs. Solar panels and battery storage provide renewable energy for sustainable operation. The system achieved a volumetric water content of 0.4 cm^3 and reduced total irrigation water delivery to 8.500 mm, demonstrating improved water efficiency compared with existing methods. This approach reduces water wastage, supports crop growth, and promotes sustainable farming [10].

The IoT-based smart irrigation system uses soil moisture, temperature, humidity, and water level sensors to monitor field conditions. The ESP8266 NodeMCU automatically controls the water pump based on soil moisture and enables remote monitoring through Wi-Fi and cloud services. Wireless sensor networks help reduce unnecessary data transmission and energy consumption. The system reduces water wastage, manual labour, and operating costs while improving irrigation efficiency and supporting sustainable agriculture. It can be adapted to different irrigation methods, including drip, sprinkler, and surface irrigation. Overall, the system provides an affordable and easy-to-maintain solution for improving crop productivity and conserving water resources [17].

III. METHODOLOGY

The Eco-Smart Irrigation System links two ESP32 boards over a LoRa radio channel. Soil and rain sensors feed the field controller, and the controller switches the valves and pump on or off according to preset limits. A cloud service lets users watch and command the setup remotely. Fig. 1 shows how the parts are connected.

A. System Architecture

The setup has a field side and a monitoring side, joined by a LoRa radio link that carries traffic both ways. In the field, the ESP32 (Rx) gathers input from a rain detector and two moisture probes, with one probe per irrigation zone [17]. It judges the readings against stored limits and tells the L298N driver what to switch, which in turn powers the magnetic valves and the 12V pump motor. A solar panel with a battery supplies this side [7]. The monitoring side uses the ESP32 (Tx). It picks up the field data from the radio link, prints it on the LCD, and forwards it to the custom IoT cloud, where the mobile app and web dashboard present it [9]. User commands go back the opposite way, from the cloud through the ESP32 (Tx) and the radio link to the field controller. A handheld remote offers one more way to watch and operate the system.

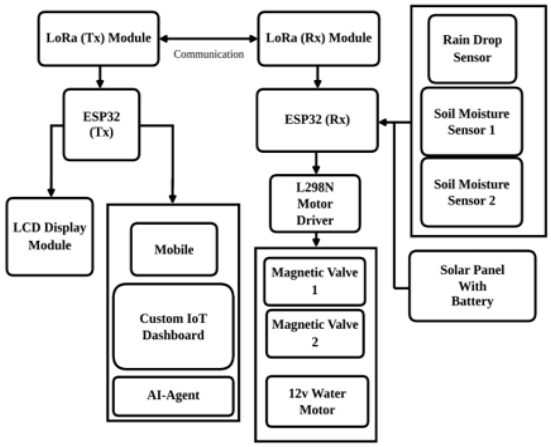


Fig. 1. Block diagram of the proposed Eco-Smart Irrigation System.

B. Sensing and Data Acquisition

Each zone has its own moisture probe, which gives a separate reading for every zone. The ESP32 (Rx) converts the probe signal into a moisture figure and compares it with that zone's limit. The rain detector acts as an extra condition: when rain is present, watering is postponed so that water is not wasted [2].

C. LoRa-Based Communication

Two LoRa modules form a long-range link that uses little power. Data moves in both directions: readings and status go to the monitoring side, and user commands return to the field. Because the radio handles this traffic, no Wi-Fi network needs to cover the field [13].

D. Irrigation Control

Every zone is judged independently. If a zone's moisture falls below its limit and no rain is detected, the ESP32 (Rx) signals the L298N driver to open that zone's valve and start the 12V motor [1]. When the zone reaches its target moisture, or when rain begins, the valve shuts, and the motor stops. Water goes only where it is needed, and the other zones are left alone.

E. Hardware Implementation

The prototype uses two ESP32 boards, two LoRa modules, two moisture probes, a rain sensor, an L298N driver, two magnetic valves, a 12V water motor, an LCD, a handheld remote, a solar panel, a battery, and power-management circuitry [19]. The ESP32 (Rx) senses and actuates in the field, while the ESP32 (Tx) manages the display and the cloud link. The L298N allows the low-current ESP32 pins to control the valves and motor, which need more current.

F. IoT Monitoring and User Control

The custom IoT cloud connects the mobile app, the dashboard and the AI agent. Users can read the moisture of Zone 1 and Zone 2, the rain status, and the state of the valves and motor, and can change those states from the app or dashboard [16]. In manual mode, the motor and each valve are operated one by one. In automatic mode, the stored limits decide. The AI agent studies the logged data to suggest suitable crops.

The handheld remote operates the motor and valves just like the mobile app. Its screen shows Y when Wi-Fi is connected and N when it is not, along with the current moisture of Zone 1 and Zone 2. With Wi-Fi on, it stays consistent with the app and dashboard. With Wi-Fi off, it still switches the devices and shows the moisture values, so the user keeps local control during a network outage.

G. Power Supply

A solar panel and a rechargeable battery power the field unit. In daylight, the panel runs the electronics and charges the battery, and at night or in weak sun, the battery takes over. This means the unit does not depend on mains electricity [11].

H. Experimental Setup and Evaluation

The prototype is tried under varied moisture levels, with and without rain. The tests cover sensor readings, two-way LoRa messaging, automatic watering and remote monitoring. They record how each zone responds, how the valves and 12V motor behave, how data is transferred, and whether the app, dashboard and field unit agree. The remote is also tested with Wi-Fi on and off to confirm that the Y/N indicator, moisture values and device control work in both cases. The moisture limit, sampling interval, LoRa settings, supply voltage and test duration are documented for repeatability.

IV. RESULTS

The developed Eco-Smart Irrigation System was built and tested for real-time field monitoring and irrigation control. The results are presented through the web dashboard (Figs. 2 to 4) and the mobile application (Figs. 5(a) and 5(b)).

A. Web Dashboard

Fig. 2 shows the Home page of the web dashboard, which plots live soil-moisture readings for both zones. At the time of capture, Zone 1 (Zone A) read 48%, and Zone 2 (Zone B) read 60%, and both were marked as Optimal. Over the logged period, Zone 1 ranged from 48% to 64% with an average of 58%, and Zone 2 ranged from 58% to 68% with an average of 63%. Each zone card also lists its own switching limits: irrigation turns on below 45% and off above 77% for Zone 1, and on below 46% and off above 69% for Zone 2. The trend chart, updated every two minutes, lets the user follow how moisture changes in each zone, and a weather tile reports the current sky condition, which was clear.



Fig. 2. Eco-Smart home dashboard showing real-time soil-moisture monitoring and irrigation status for two zones.

B. AI-Based Soil and Crop Analysis

The AI & Analytics page lets the user upload a photograph of the field and send it for analysis, as shown in Fig. 3. For the test image, the module classified the land as barren, with only soil, small stones and a few scattered weed sprouts, and no crop beds or cultivated plants. It identified the soil as a coarse sandy loam to gravelly red-brown type, with good drainage and aeration but low water-holding capacity and low organic matter, which makes the upper layer dry out quickly in warm weather.

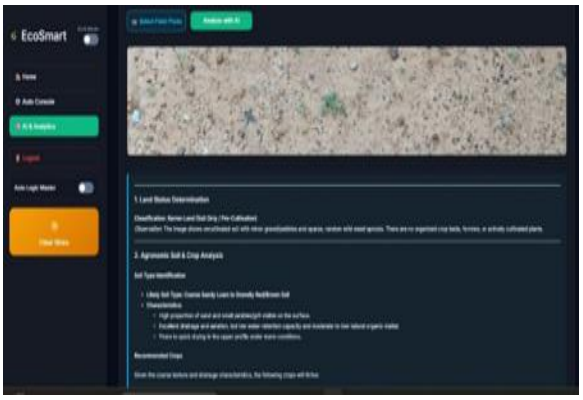


Fig. 3. AI & Analytics page showing the uploaded field photograph and the land status and soil type identified by the AI module.

Fig. 4 shows the rest of the same report. Based on the soil type, the model suggested crops from three groups: legumes and pulses (groundnut, pigeon pea, cowpea and chickpea), cereals and millets (pearl millet, finger millet, sorghum and maize), and tuber and root crops (sweet potato, cassava and carrot). It gave a target moisture range of 50% to 65%, explaining that sandy soils drain quickly, so moisture should stay above 50% to avoid stress and below 70% to limit nutrient loss through drainage. The report also combined the live telemetry with the thresholds stored in the system. It noted that the Zone 1 off threshold of 77% was too high for this soil and advised lowering it to between 65% and 70%. Because Zone 1 was only a few percentage points above its on threshold, it advised raising the on threshold to 50% and switching on Auto Mode. It also recommended mixing farmyard manure or compost into the soil before planting to improve water retention.



Fig. 4. AI-generated crop recommendations, target moisture range and threshold advice based on live telemetry.

C. Mobile Application

Fig. 5(a) shows the Field Status page of the mobile application. The gauges display the current soil moisture of each zone, 56% for Zone 1 and 36% for Zone 2. A System Sync Live indicator at the top confirms that the phone is receiving live data from the system. A Sign Out button and a menu icon are also provided, and the Soil Moisture Dynamics panel with its Live Telemetry label begins below the gauges.



Fig. 5. Mobile application: (a) Field Status page; (b) live telemetry and manual control.

Fig. 5(b) shows the live telemetry panel of the mobile application. Zone 1 (Zone A) has a current moisture of 56%, with a minimum of 54%, a maximum of 59% and an average of 56%. Its limits are below 45% and above 77%, and it is marked Optimal. Zone 2 (Zone B) has a current moisture of 36%, with a minimum of 34%, a maximum of 42% and an average of 37%. Its limits are below 46% and above 69%, and it is marked Dry (Trigger) because its moisture is below its lower

limit. The trend chart plots both zones from 11:20 am to 11:23 am, and the tabs above it switch between all zones, Zone 1 (A) and Zone 2 (B). Below the chart, the Manual Control section provides a Master Motor (Primary Pump) switch for operating the pump from the phone.

V. DISCUSSION

The test results demonstrate that the proposed system can integrate field sensing, wireless communication, and irrigation control into a single platform. LoRa communication enables sensor information to be transferred between the field unit and the receiving unit without requiring continuous Wi-Fi connectivity at the sensing location.

The zone-based soil-moisture monitoring allows irrigation decisions to be made according to the condition of individual field areas. The rain sensor provides an additional condition for avoiding unnecessary irrigation. Manual control through the mobile application provides flexibility when direct user intervention is required.

The combination of automatic and manual modes makes the system suitable for different irrigation conditions. However, the current prototype was evaluated under controlled testing conditions, and long-term field testing with different soil types, crops, weather conditions, and larger agricultural areas is required for further validation.

VI. CONCLUSION

The Eco-Smart Irrigation System was successfully designed and implemented for automated irrigation and remote field monitoring. The system integrates ESP32 controllers, LoRa communication, soil-moisture sensors, a rain sensor, solenoid valves, and a water motor to provide zone-based irrigation control.

The implemented prototype demonstrated successful sensor-data acquisition, wireless communication, real-time monitoring, and both automatic and manual irrigation control. The mobile application further enables users to monitor field conditions and control the irrigation system remotely.

Overall, the proposed system provides a practical IoT-based approach to irrigation management. Future improvements can include larger-scale field deployment, additional irrigation zones, weather-data integration, and AI-based irrigation prediction.

VII. FUTURE SCOPE

The proposed Eco-Smart Irrigation System can be further enhanced by incorporating AI-based irrigation prediction, image-based pest and disease detection, multi-zone irrigation control, crop-specific watering, and predictive maintenance. The ESP32-CYD (Cheap Yellow Display), an ESP32 board with an integrated touchscreen display, can be used in future versions to replace the separate LCD module and provide a compact on-site touch interface for viewing soil-moisture values, rainfall status, and valve and motor states, and for switching between automatic and manual modes without a smartphone. Advanced data analytics can be used to analyse irrigation patterns and optimise water usage. Future evaluation can quantify improvements using parameters such as water consumption reduction, irrigation response time, soil-moisture control accuracy, LoRa communication reliability, and energy consumption. These enhancements can make the system more autonomous, efficient, reliable, and suitable for large-scale agricultural applications.

REFERENCES

[1]. Y. Ware et al., “Smart automated irrigation system with pest control & IoT monitoring,” in *Proc. 13th Int. Conf. Intell. Syst. Embedded Des. (ISED)*, Raipur, India, 2025, pp. 321–327.

[2]. C. Jada and N. Varshitha, “Design and analysis of a smart irrigation control system,” in *Proc. IEEE Int. Students’ Conf. Electr., Electron. Comput. Sci. (SCEECS)*, Bhopal, India, 2025, pp. 1–6.

[3]. B. Y. S. S. Murthy, C. B. K. Reddy, S. Jilani, and M. Sindhwani, “Smart irrigation system,” in *Proc. 1st Int. Conf. Sustain. Technol. Power Energy Syst. (STPES)*, Srinagar, India, 2022, pp. 1–4.

[4]. K. Sumalatha and K. Harshdeep, “Smart monitoring and irrigation regulation via IoT and cloud,” in *Proc. 8th Int. Conf. I-SMAC (IoT Social, Mobile, Analytics Cloud)*, Kirtipur, Nepal, 2024, pp. 88–94.

[5]. D. R. Sharma, V. Mishra, and S. Srivastava, "Enhancing crop yields through IoT-enabled precision agriculture," in *Proc. Int. Conf. Disruptive Technol. (ICDT)*, Greater Noida, India, 2023, pp. 279–283.

[6]. R. Habib, Al-Amin, A. Alrashed, F. J. Mouly, and S. D. Avi, "Smart irrigation systems: An overview of current trends and technologies," in *Proc. 4th Int. Conf. Sentiment Anal. Deep Learn. (ICSADL)*, Bhimdatta, Nepal, 2025, pp. 642–646.

[7]. M. Z. Falah, A. N. Afandi, H. Abdillah, Sujito, A. Haris, and W. A. Kusuma, "Implementation of solar power plants (PLTS) for pump system operation in environmentally friendly vertical gardens based on Internet of Things," in *Proc. Int. Conf. Adisutjipto Aerosp. Electr. Eng. Informat. (ICAAEEI)*, Yogyakarta, Indonesia, 2024, pp. 1–7.

[8]. P. Rekha, V. P. Rangan, M. V. Ramesh, and K. V. Nibi, "High yield groundnut agronomy: An IoT-based precision farming framework," in *Proc. IEEE Global Humanitarian Technol. Conf. (GHTC)*, San Jose, CA, USA, 2017, pp. 1–5.

[9]. H. Gupta, A. Sisodia, S. Kumar, and S. Bhatnagar, "IoT-based smart green farming system using Raspberry Pi with cloud and mobile integration for environmental monitoring and water management," in *Proc. 14th Int. Conf. Syst. Model. Adv. Res. Trends (SMART)*, Moradabad, India, 2025, pp. 153–158.

[10]. V. Rakeshdatta, H. M. N., R. Suresh, A. K. P. Venkata, and S. S. Reddy, "AI-driven adaptive smart irrigation system using machine learning for sustainable agricultural water management," in *Proc. 2nd Int. Conf. Softw., Syst. Inf. Technol. (SSITCON)*, Tumkur, India, 2025, pp. 1–6.

[11]. F. Y. Abdullah, M. T. Yaseen, and Y. S. Sheet, "Smart eco-friendly and low-cost farming control system," in *Proc. 5th Int. Congr. Human-Comput. Interact., Optim. Robot. Appl. (HORA)*, Istanbul, Türkiye, 2023, pp. 1–5.

[12]. K. Ingale, A. Vidhale, S. Vikhar, I. Wagh, and A. Waghmare, "Enhancing crop yields with smart agriculture systems using solar trackers," in *Proc. 2nd Int. Conf. Futuristic Technol. (INCOFT)*, Belagavi, India, 2023, pp. 1–7.

[13]. K. K. S. and C. S. Jain, "Smart agriculture with fertilizer/pesticide recommendation system," in *Proc. 3rd Int. Conf. Smart Syst. Appl. Electr. Sci. (ICSSES)*, Tumakuru, India, 2025, pp. 1–6.

[14]. S. C. Boovaneswari, S. S., and S. P., "Intelligent water management system utilising AI for precision agriculture," in *Proc. Int. Conf. Syst., Comput., Autom. Netw. (ICSCAN)*, Puducherry, India, 2024, pp. 1–5.

[15]. S. Voigt, A. Willert, W. Mende, T. Zschau, T. Oehme, and R. Zichner, "Environmentally friendly and low-cost monitoring system for plant and agriculture fields," in *Proc. Smart Syst. Integr. Conf. Exhib. (SSI)*, Brugge, Belgium, 2023, pp. 1–4.

[16]. R. Balamurugan, P. Girishanth, T. Dharshan, B. Dhivakar, and S. Dharshan, "Smart irrigation system for precision farming," in *Proc. 10th Int. Conf. Smart Struct. Syst. (ICSSS)*, Chennai, India, 2025, pp. 1–5.

[17]. M. B. Tephila, R. A. Sri, R. Abinaya, J. A. Lakshmi, and V. Divya, "Automated smart irrigation system using IoT with sensor parameter," in *Proc. Int. Conf. Electron. Renewable Syst. (ICEARS)*, Tuticorin, India, 2022, pp. 543–549.

[18]. R. Bindal, M. Kaur, and R. Tandon, "Smart irrigation for soil moisture prediction using hybrid AI and fog computing," in *Proc. IEEE 14th Int. Conf. Commun. Syst. Netw. Technol. (CSNT)*, Bhopal, India, 2025, pp. 887–891.

[19]. S. Madhu, S. K. P. S., and S. L. P., "Smart agriculture: A crop monitoring system to empower agricultural field using IoT," in *Proc. Emerging Technol. Intell. Syst. (ETIS)*, Trivandrum, India, 2025, pp. 1–6.

[20]. K. Murugan, S. Priya, and K. Selvarani, "Agriculture water management system using IoT," in *Proc. Int. Conf. Emerging Technol. Eng. Appl. (ICETEA)*, Tamil Nadu, India, 2025, pp. 1–6.