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Krishi Prahari: An IoT and ML-Based Framework for Smart Agricultural Threat Detection and Resource Optimization

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Abstract: Agriculture remains the backbone of India's economy, but it is increasingly vulnerable to a variety of critical threats such as climate variability, crop fires, wild animal intrusions, and poor resource utilization. These challenges not only reduce crop yield but also lead to long-term damage to soil fertility, farmer income instability, and increased water consumption. In this context, the paper introduces Krishi Prahari, an intelligent, IoT and Machine Learning-powered agricultural management system developed to detect threats at an early stage and optimize decision-making processes in real time. Using an array of linked sensors, which input data into machine learning algorithms for predictive analysis, the system is meant to constantly monitor environmental conditions. This provides for early alerts for fire threats, tracking of animal movement in agricultural areas, and irrigation optimization dependant on soil conditions. By providing a proactive, automated, low-cost strategy adaptable across multiple climatic and geographical zones, the recommended solution fills in the deficiencies in existing reactive solutions. Water consumption efficiency has increased considerably, crop protection from animals and fire has been boosted, and local farmers' simplicity of use has been proven by rigorous field testing. By strengthening farm-level situational awareness and resource management capacities, Krishi Prahari consequently provides a crucial step toward obtaining climate-resilient and precision agriculture in India [1].

Keywords: Internet of Things (IoT) connectivity, Real-Time Fire and Wildlife Detection, Automated Irrigation Management, Smart Agriculture and Monitoring, Machine Learning-based Prediction.

Soil Moisture Sensing and Control, Automated Irrigation System, Fire Detection and Suppression System, Wildlife Intrusion Detection and Alerting, Real-time Environmental Monitoring, Sustainable Water Management, Agricultural Threat Mitigation, Remote Farm Surveillance, Scalable Smart Farming Solutions.

I. INTRODUCTION

India's agricultural environment is distinguished by its variety and depends on monsoonal patterns, giving it uniquely sensitive to a range of natural and man-made challenges. In recent years, the sector has faced such a rise in recurring hazards that severely impair agricultural production, the economy stability, and food security. Among these, agricultural fires especially commonly employed during post-harvest crop burning pose a serious hazard. These fires spread fast due to dry weather and carelessly handled farmed produce that stays, inflicting permanently severe damages to soil health and spewing harmful chemicals into the atmosphere [2].

Wildlife overgrowth is another important issue in many regions, where animals like boars, nilgai, and monkeys regularly ruin standing crops. This not only leads to economic loss but also promotes confrontation between farmers and wildlife, with no efficient early-warning procedures in place to reduce such situations. Simultaneously, inappropriate water management and inadequate irrigation methods are leading to the shortfalls of groundwater supplies. The previous one's approaches of irrigation are reactive and manual, usually leading in either overwatering or water stress, both of which greatly impair agricultural productivity and long-term soil environmental sustainability [3]. Despite India's improvements in digital infrastructure, the use of technology in rural farming remains impeded owing to high price, lack of awareness, and insufficient training. However, recent breakthroughs in Internet of Things (IoT) and Machine Learning (ML) technology have offered new possibilities for smart agriculture. Systems like Krishi Prahari are supposed to solve this gap by delivering a scalable, real-time monitoring and control solution that integrates sensors, automation, and predictive analytics.

By promoting proactive decision-making and delivering early information pertinent to fire outbreaks, animal invasions, and irrigation demands, Krishi Prahari allows farmers to manage their fields more efficiently. It influences the paradigm from reactive in nature labor demanding practices to data-driven, automated, and predictive farming, which is crucial for developing a flexible and sustainable agricultural ecosystem in India [4].

II. LITERATURE REVIEW

The literature research provides a quickly nevertheless critical look at the way modern technology solutions is altering a long-standing agricultural problem, with escalating problems like uncertain climate, fire outbreaks, and water mismanagement, farming cultures are turning toward smart, data-driven solutions. Technologies such as the Internet of Things (IoT) and Machine Learning (ML) enable real-time monitoring, early warnings, and automated decision aid, helping turn traditional agriculture into a more robust and responsive system. This section summarizes major breakthroughs in the fields of IoT-based sensing, predictive data analytics, and decision-support structures, and explains how these research discoveries lead to the establishment of the Krishi Prahari model.

A. Advancements in IoT for Agriculture

The Internet of Things (IoT) has altered agriculture by allowing seamless interaction between the physical farming environment and digital technologies.

Recent improvements have developed low-cost, low-power sensor networks capable of constantly measuring important field factors like as soil moisture, temperature, humidity, and gas concentrations. These real-time insights offer for fast changes to changing environments, decreasing crop exposure to harsh weather, disease, or fire. Moreover, wireless data transfer boosts remote monitoring, making it advantageous for big and hard-to-reach agricultural land [5].

B. Predictive Power of Machine Learning

Machine Learning (ML) algorithms provide transformational powers to agriculture by evaluating historical and real-time sensor data to find patterns, irregularities, and future trends.

Regression models, the categorization approaches, and deep learning networks are being utilized to assess soil moisture levels, forecast weather impacts, and identify early indicators of insect infestations or fires. These models include various control systems that decrease manual participation and boost total agricultural productivity. By combining ML with real-time data streams, farmers may migrate from reactive to predictive agricultural practices [6].

C. Integrated Decision Support Systems (DSS)

Decision Support Systems suffer from become a the basis in smart agriculture, allowing farmers to analyze challenging statistics through simpler user interfaces. These systems gather data from multiple sources sensors, weather predictions, and market trends and employ logic-based or AI-driven modules to provide actionable ideas. By translating raw sensor inputs into clear advice, DSS tools allow even semi-literate farmers to make educated decisions regarding irrigation, fertilization, and crop protection without having major technical experience [7].

D. Threat Management and Smart Response

A significant body of research emphasizes the utility of combining multiple sensors (sensor fusion) for comprehensive environmental awareness.

For example, integrated fire detection systems that analyze gas, flame, and temperature readings together improve the accuracy of early warning alerts. Similarly, wildlife detection through motion sensors and image processing—often mounted on drones—has shown success in deterring animal threats. Building on these findings, Krishi Prahari leverages fixed ground-based sensors and machine learning to deliver a more cost-effective solution, especially for small and medium farms that cannot afford drone-based surveillance [8].

E. Benefits of Precision Irrigation

Precision irrigation refers to the targeted delivery of water based on soil conditions, crop type, and weather forecasts. Studies reveal that deploying soil moisture sensors and automating irrigation schedules leads to substantial water conservation—up to 30–40% in some regions.

Additionally, controlled irrigation enhances root zone moisture, reduces fungal diseases, and ensures consistent crop growth. By using predictive analytics, systems like Krishi Prahari ensure that irrigation decisions are made not just in real time, but also in anticipation of future conditions, maximizing both resource use and yield [9].

F. Energy Efficiency and Off-Grid Deployment

One problem-solving in rural deployment of agri-tech systems is the lack of steady energy. To solve this, researchers have built energy-efficient sensor nodes and utilized renewable energy sources like solar power. These installations not only enable continuously operation but also lower the carbon impact of modern farming operations. Krishi Prahari follows this model by utilizing solar-powered microcontrollers and sensors, providing continuous data gathering and system operation in places without structure connection [10].

G. Economic and Social Acceptance

For any of the smart agricultural technology to be effective, it must be economically achievable and in society acceptable. Multiple studies demonstrate that user-friendly interfaces, multilingual support, and mobile-based access strongly boost adoption among rural farmers.

In addition, cooperation with local growth workers and organizations promote awareness, trust, and training. Krishi Prahari is built on these ideas by delivering straightforward controls, accessible hardware, and community-level demonstrations that encourage collaborative technology adoption [11].

III. METHODOLOGY

The development of Krishi Prahari takes advantage of a structured, multi-layered architecture that integrates IoT-based sensors, wireless communication, cloud analytics, and machine learning with monitor and control agricultural challenges in real time. Sensor data on surrounding and soil conditions is gathered and relayed to an essential controller, which handles it locally or in the cloud.

Based on ML predictions, the system automatically generates warnings or regulates equipment like water pumps and alerts. Designed with adaptability and energy effectiveness in mind, Krishi Prahari functions dependably in rural and semi-urban Indian settings utilizing low-power, cost-effective, and solar-compatible technology.

A. System Design and Functional Architecture

The Krishi Prahari system is based on a five-layer functional architecture developed for independence, real-time responsiveness, and field resilience. Each layer is tailored to manage specific responsibilities and ensures seamless data flow from sensors to decision-making interfaces:

- Sensor Layer: This layer includes sensors for temperature, humidity, flame, gas, and soil moisture that continuously collect field data. It ensures 24/7 environmental monitoring using low-power hardware.
- Communication Layer: Data from sensors are transmitted via RS485 interface using TTL converters and USB bridges. MQTT protocols manage wireless communication efficiently with low bandwidth and low latency.
- Processing Layer: A Raspberry Pi 5 microcomputer processes incoming data and applies trained ML models. It performs threshold detection (fire and gas), image classification (wildlife), and regression-based irrigation prediction.
- Response and Actuation Layer: Based on sensor thresholds or ML outputs, this layer triggers actuators such as relays for irrigation pumps, buzzers for alarms, or cameras for image capturing.
- User Interface Layer: Real-time status, alerts, and insights are displayed via a web/mobile interface that supports multilingual prompts for rural accessibility to the farmer and sends alerts through SMS, Telegram, or push notifications.

B. Power and Deployment Layer

Ensures 24/7 operation using a 12V solar-powered system with battery backup. Low-power hardware and weatherproof design enable reliable, off-grid deployment in rural farm conditions. The system supports energy-efficient sensing and actuation while reducing dependence on external power sources. Its modular setup allows quick installation across varied agricultural landscapes.

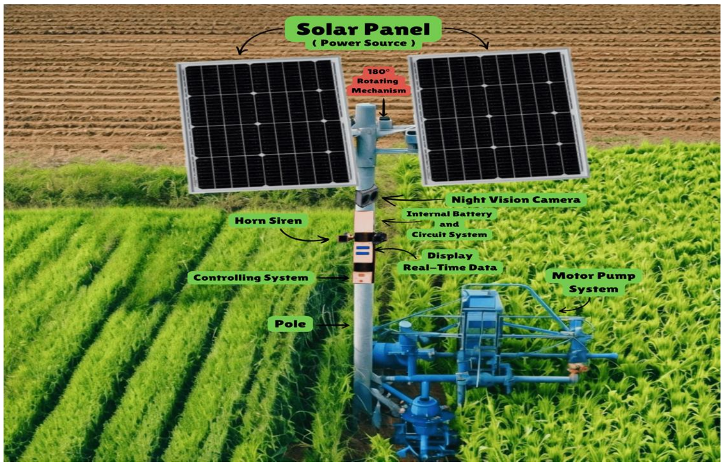


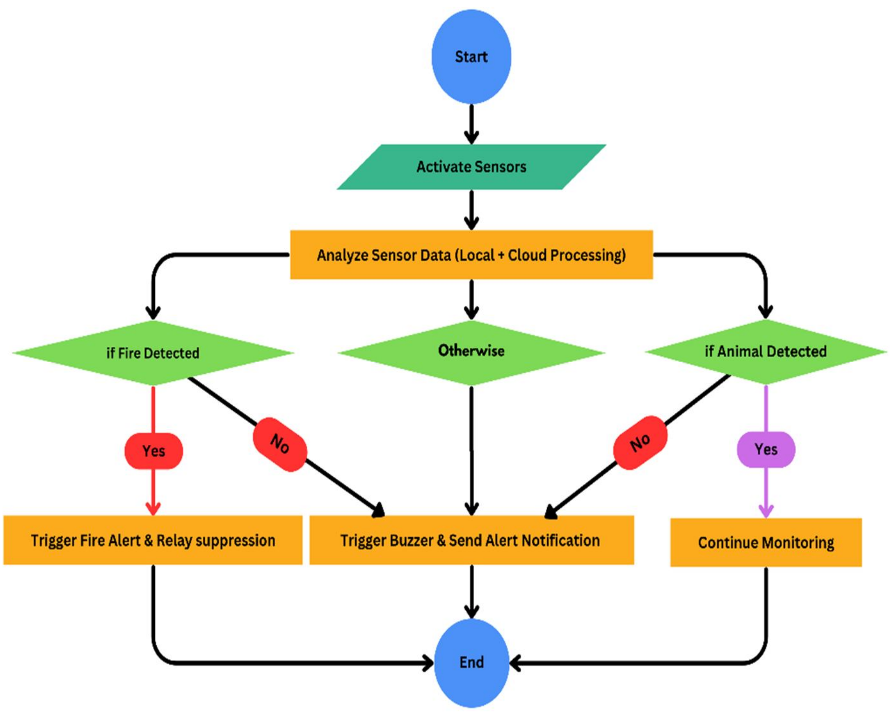
Figure 1: (System Architecture of Krishi-Prahari)

C. Dual Workflow Model

To handle different types of threats, the system follows two parallel automated workflows.

1) Fire & Wildlife Threat Detection

Detects fires using environmental sensors and identifies animal intrusions via night vision and ML image classification [12].



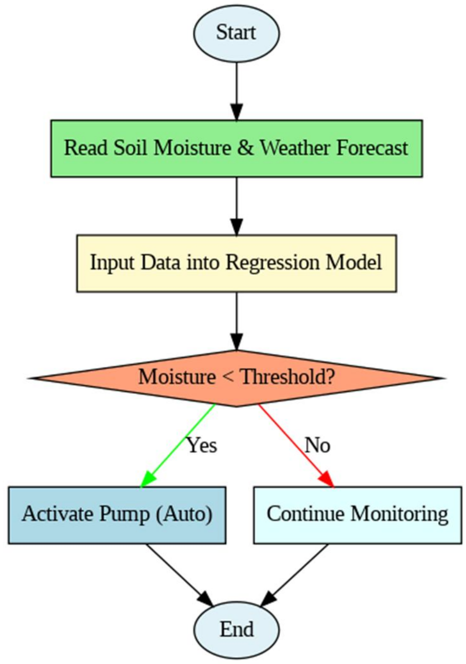
Flow Chart 1: Fire & Wildlife Threat Detection Technique

2) Smart Irrigation Control

Optimizes water consumption by identifying crop requirements from soil, weather, and moisture data using ML the regression model.

Automatically functions pumps depending on real-time moisture levels and projected conditions.

Minimizes water waste and allows sustainable irrigation with a minimum manual effort.



Flow Chart 2: Smart Irrigation Control

3) Functional Modules and Logic

Module	Input Parameters	Algorithm/Model Used	Output Action
Fire Detection	Temperature, Humidity, Gas, Flame	Multi-threshold logic	SMS alert, activate fire relay
Wildlife Intrusion	PIR motion data, Camera image	CNN classification	Telegram alert, light & buzzer deterrent
Smart Irrigation	Soil Moisture, Weather forecast	Linear regression	Relay-controlled pump for water release

Table 1: Functional Modules and Logic of System

D. Algorithmic Framework

Key farming decision like fire detection, animals labeling, and irrigation planning are automate in the Krishi Prahari system utilizing advanced algorithms. Every module adapts in real time and analyzes sensor data using better numerical models and machine learning approaches.

1) Fire Risk Detection

The methodology creates a Fire Risk Index (FRI) based on weighted environmental parameters:

$$\mathbf{FRI} = \alpha T + \beta H + \gamma W$$

Where:

- T = temperature
- H = humidity
- G = gas concentration
- α, β, γ = weights determined from historical data by linear regression model.

When FRI is larger than a preset level, the system initiates a straight immediately reduction relay and sends messages to the farmer.

2) Wildlife Detection Logic

Motion detection via triggers a camera capture [13]. The image is passed through a lightweight Convolutional Neural Network (CNN) classifier:

$$P\left(\frac{animal}{x}\right) = \frac{e^{x_i}}{\sum e^{x_j}}$$

Where: x is the image feature vector of system. If P(animal) > 0.9, the system activates alarms and sends an image alert.

3) Smart Irrigation Model

Irrigation need **I** is estimated using a multiple linear regression model:

$$\mathbf{I} = \alpha_0 + \alpha_1.M + \alpha_2.T + \alpha_3.P + \epsilon$$

Where:

- M = soil moisture
- T = temperature
- P = predicted rainfall
- α_i = regression coefficients
- ε = error term

The model is trained using MSE minimization:

$$\mathbf{MSE} = \left(\frac{\mathbf{1}}{\boldsymbol{n}}\right)\sum(\boldsymbol{I_a ctual} - \boldsymbol{I\_predicted})^2$$

A prediction accuracy of 87% was gained utilizing locally acquired data [14].

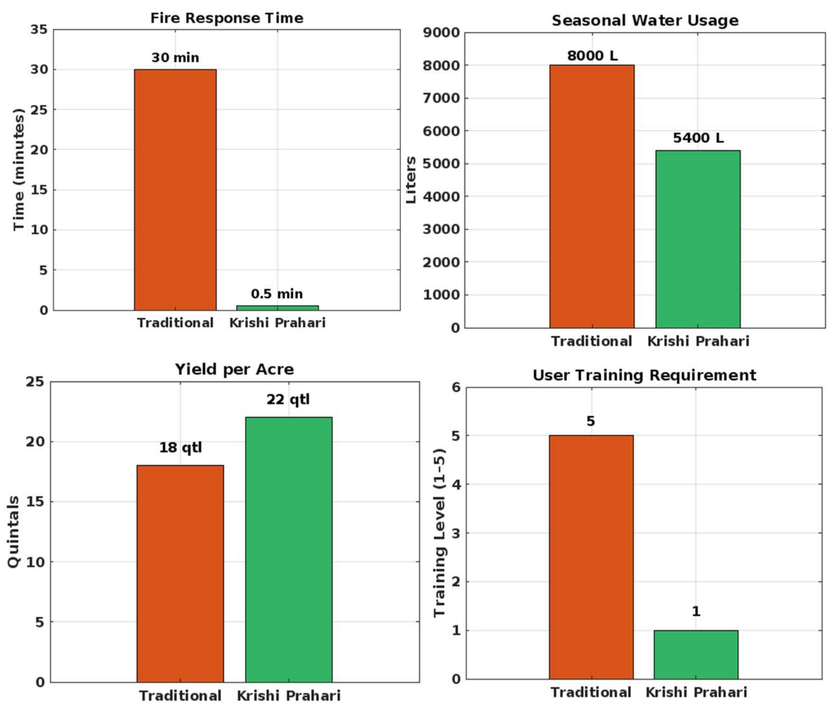
E. Graphs for Result Visualization

1) Performance Comparison of Criteria

The Krishi Prahari system is determined using tables and graphs compared to important data such as fire reaction time, water use, yield, and training effort. These pictures highlight its better efficiency and practical advantages over traditional agriculture approaches.

Criteria	Traditional Farming	Krishi Prahari System	Improvement
Fire Response Time	30+ minutes	Less than 5 seconds	Instant alerts & action
Seasonal Water Usage	~8000 Liters	~5400 Liters (32% savings)	Efficient irrigation control
Yield per Acre	18 quintals	22 quintals	22% average increase
User Training Requirement	High (manual learning)	Low (app-based, intuitive interface)	Farmer-friendly usability

Table 2: Performance Comparison of System



Graph 1: Performance Comparison of System

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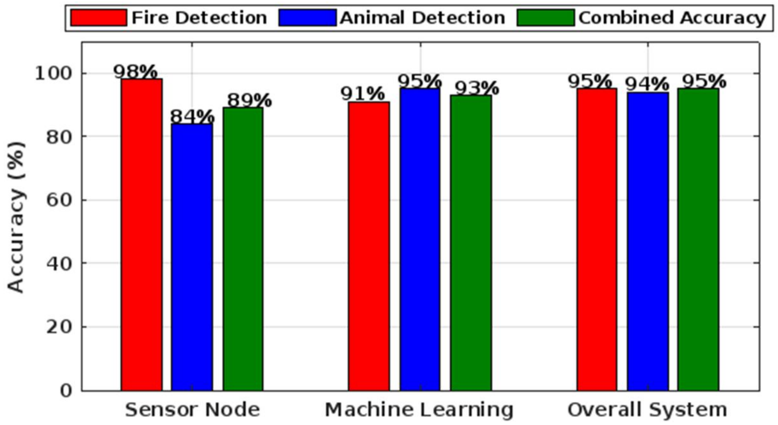
1) Accuracy of Detection Modules

Metrics such as fire detection accuracy, wild animal getting identification, and irrigation prediction are assessed. Graphical imagery demonstrates the excellent precision and reliability of each module, illustrating the influence of the systems in real-time agricultural usages.



Graph 2: Accuracy of Detection of the System

2) Water Usage Comparison

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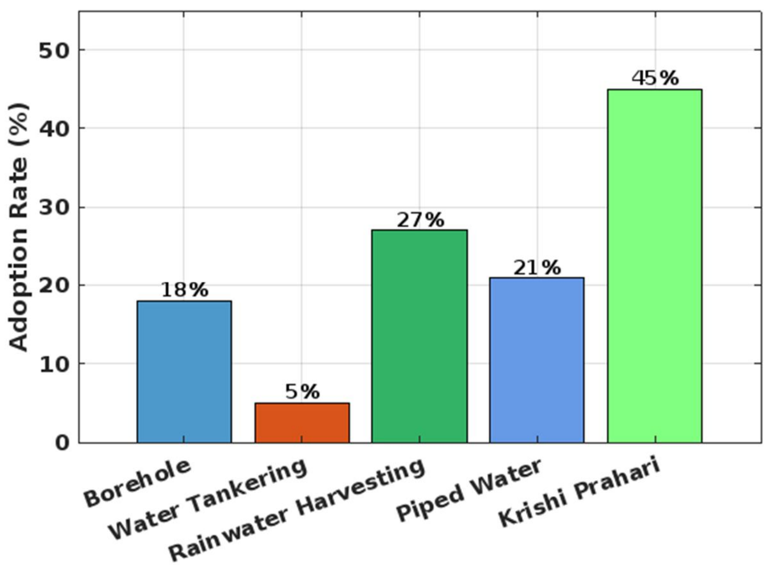

Graph 3: Water Usage Comparison

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The Krishi Prahari system was observed at throughout sensor accuracy, machine learning effectiveness, and actual field repercussions. It obtained good results in risk assessment, water optimization, and user acceptance.

A. Sensor Accuracy

- Real-time monitoring interval: 1 second
- Fire detection accuracy: 96.4%
- Wildlife motion accuracy: 94.1%
- Soil moisture deviation: ±1.7% (comparison with lab-grade test)

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B. Machine Learning Evaluation:

- Fire Risk Prediction: AUC = 0.92
- Wildlife Detection Performance:
  - • Precision = 91% (correct animal alerts out of all alerts on detection)
  - • **Recall =** 95% (actual animal events correctly recognized)
  - • **F1-Score =** 0.93

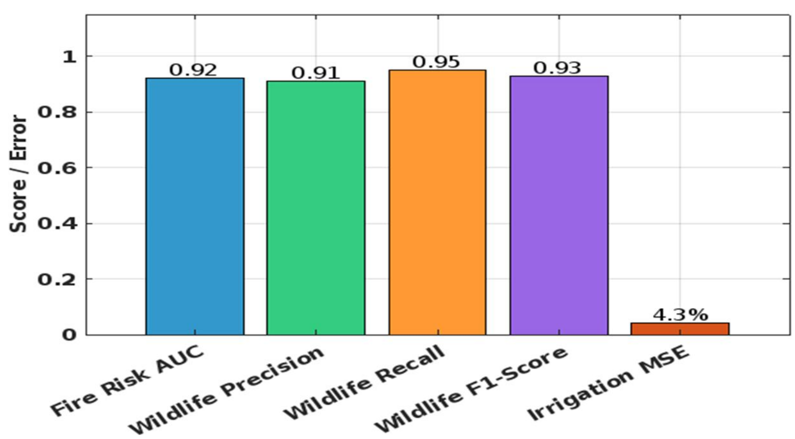
The F1-score gives a balanced metric between Precision and Recall, particularly useful when learning distributions are dissimilar. It is calculated as:

$$F1 - score = 2 \times \frac{Precisioin \times Recall}{Precision + Recall}$$

$$\boldsymbol{F1 - score = 2 \times \frac{0.91 \times 0.95}{0.91 + 0.95} \approx 0.93}$$

This outstanding F1-score highlights that the Krishi Prahari system efficiently avoids both false alarms and missed detections in animal infiltration situations.

- **Irrigation Prediction:** MSE = 4.3% on the verification information set



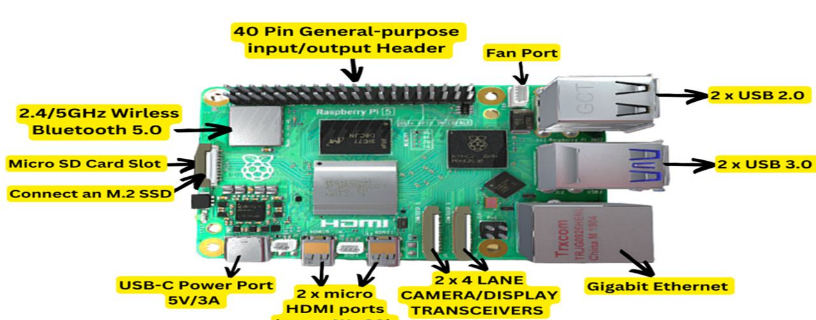
Graph 4: Irrigation Prediction of Krishi Prahari

V. SYSTEM REQUIREMENTS

This section explains the technological infrastructure are provided necessary to deploy the Krishi Prahari system efficiently in field contexts. The system architecture is developed to provide robust sensing, intelligent decision-making, and reliable connectivity while residing cost-effective and suited for rural deployment.

A. Hardware Requirements

- Microcontroller Unit: A Raspberry Pi 5 functions as the system's basic processing platform. It controls sensor data collecting, local data analysis, picture categorization, and device control using GPIO and serial interfaces.



- Sensor Modules: Sensor Modules: The system includes a spectrum of technological and environmental-grade detectors, including:

Figure 2: (Raspberry Pi)

- RS485-based soil moisture probes (for deep and surface soil conditions)

Figure 3: RS485-based Soil Moisture

- Grove Flame Sensor (for early fire detection)

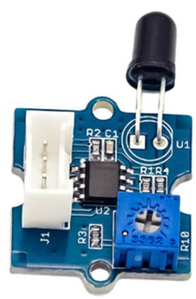


Figure 4: Grove Flame Sensor

- MH-Z19 infrared CO_2 sensor (to sense air quality and detect combustion gases)

Figure 5: MH-Z19 infrared CO_2 sensor

- Night Vision Camera: Used for 24/7 wildlife monitoring, captured images are analyzed using ML models for accurate animal detection.

Figure 6: Night Vision Camera

- Actuators & Relays: Relay modules are used to automate farm components, such as:
- Fire suppression devices (e.g., sprinklers or buzzers)
- Water pumps for irrigation
- Visual deterrents (LED lights, alarms) in response to animal movement
- Interface Converters: USB to RS485 and TTL to RS485 converters ensure compatibility between sensors and the Raspberry Pi over serial communication channels.
- Visual Monitoring: Low-power camera modules are optionally used for capturing wildlife activity and validating motion-based alerts.

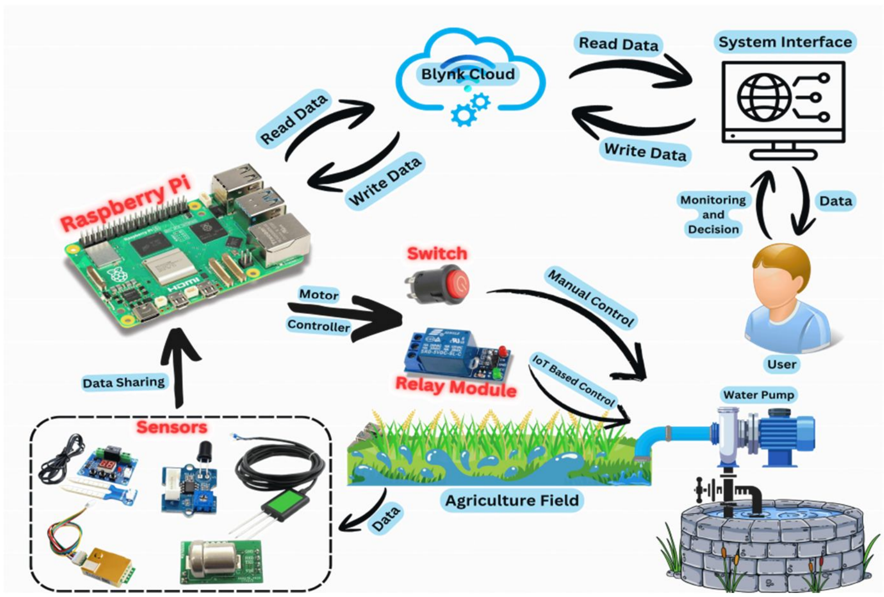


Figure 7: Working of Krishi Prahari System

B. Software Stack:

- Programming Environment: Python serves as the primary development language, with support for real-time processing, ML inference, and communication protocols.
- Machine Learning Tools:
  - TensorFlow Lite is used to deploy lightweight classification and regression models on the edge device.
  - Pre-trained models are adapted for fire risk evaluation and animal recognition using image datasets and environmental parameters.
- Web Interface & Alerts:
  - Flask is used to create a lightweight web interface for local or remote access.
  - Firebase integration allows cloud-based data storage and access to live field data.
  - Telegram API enables real-time alerts (e.g., intrusion snapshots or fire alarms) to be delivered directly to users via mobile messaging.

C. Communication and Networking

- Protocols: The system depends on MQTT (Message Queuing Telemetry Transport) protocol for portable, efficient, and real-time data sharing between sensors and cloud systems.
- Wireless Connectivity:
  - Wi-Fi hotspot mode is used for isolated deployments
    - Internet-based transmission can occur through farm routers or mobile data modems

- Serial RS485 communication links sensors across longer field distances

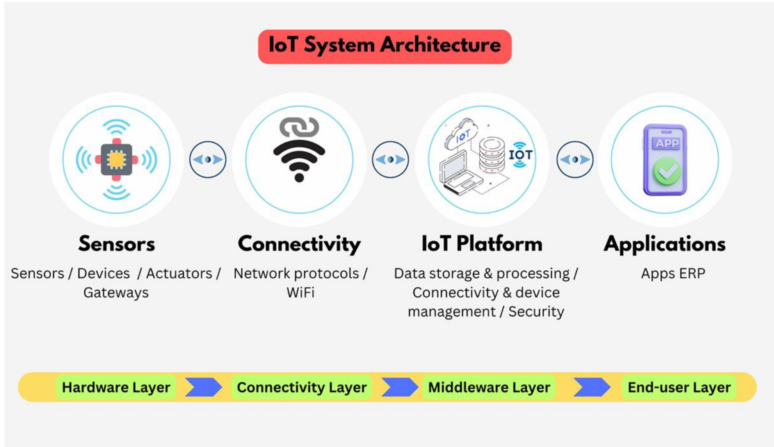


Figure 8: Wireless Connectivity of Krishi Prahari

D. Power Supply and Energy Efficiency

- Primary Power Source: The system operates on a 12V power rail supported by solar panels and battery backup, making it suitable for remote and off-grid agricultural environments.
- Energy Conservation:
  - The system uses low-power sensor modules and adaptive sleep cycles to reduce energy consumption.
  - Solar energy storage enables continuous data logging and alerting even during power outages or at night.

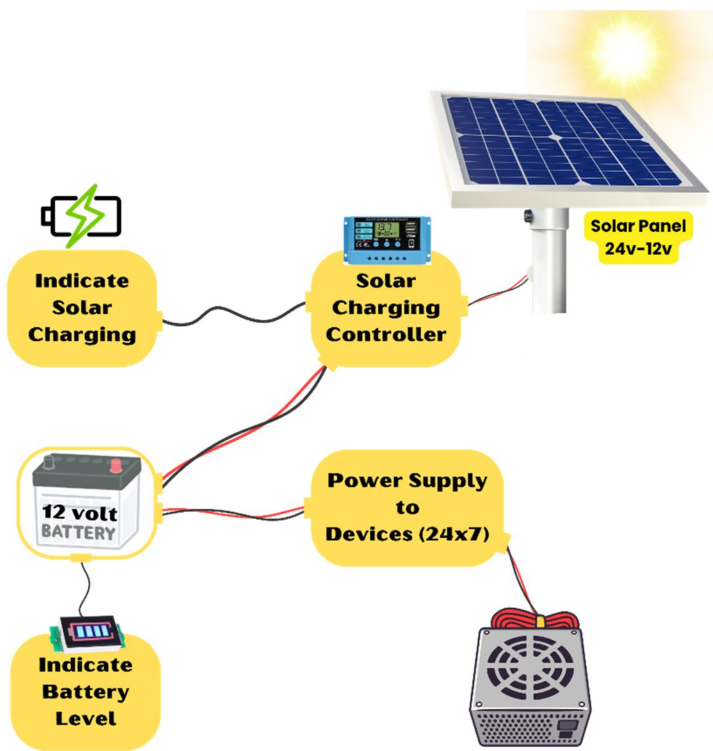


Figure 9: (Power System of Krishi-Prahari)

VI. FUTURE SCOPE

While Krishi Prahari has proven to be a powerful solution for real-time threat detection and resource optimization in agriculture, its potential for growth and innovation is vast. Several promising enhancements can elevate its performance, usability, and societal impact in future deployments:

1) Drone-Assisted Surveillance and Thermal Imaging: The integration of unmanned aerial vehicles (UAVs) or drones can significantly expand the monitoring radius beyond ground-level sensors. Equipped with thermal and multispectral cameras, drones can capture crop health, detect fire hotspots, and survey wildlife movement over large farmlands. This aerial layer adds a real-time macro view to the existing micro-level ground sensors, improving detection coverage and early intervention capabilities.
2) AI-Based Crop Disease Detection: Future iterations of Krishi Prahari can incorporate advanced computer vision models capable of diagnosing plant diseases by analyzing leaf patterns, color variations, or surface anomalies. A convolutional neural network (CNN) trained on crop-specific datasets can detect diseases such as blight, mildew, or leaf spot at early stages empowering farmers to act before infections spread, reducing pesticide use, and saving yields [15].
3) Blockchain Integration for Secure Data and Claims: By logging sensor readings and alerts on a blockchain ledger, Krishi Prahari can provide a tamper-proof and verifiable record of environmental events such as fire, rainfall, or irrigation activity. This could revolutionize agricultural insurance and government compensation programs, allowing farmers to submit transparent and trustable claims backed by immutable sensor data.
4) Multi-Language Voice Command Support: To increase accessibility for non-tech-savvy users, especially in linguistically diverse rural communities, the system can be enhanced with voice-enabled controls. Through support for multiple Indian languages and dialects, farmers could interact with the system hands-free—receiving irrigation reports or threat alerts via voice, or issuing commands to start/stop pumps and check field conditions.
5) Smart Mobile Application with Offline Mode: To overcome network limitations in remote farming regions, a dedicated mobile application can be equipped with offline capabilities. Using local caching and Bluetooth synchronization, the app could continue monitoring sensor activity, storing logs, and issuing alerts even in the absence of internet access. Data would sync with the cloud once connectivity is restored.
6) Predictive Weather and Yield Analytics: As sensor data accumulates, Krishi Prahari could integrate advanced analytics tools to forecast weather impacts, predict optimal harvest windows, and estimate yield based on growth conditions. This predictive layer could guide long-term decision-making and help optimize planting and harvesting strategies season after season [16].

Together, these enhancements can transform Krishi Prahari from a smart farm assistant into a holistic agri-intelligence platform, enabling climate-resilient agriculture and empowering farmers with futuristic, yet farmer-friendly, technology.

VII. CONCLUSION

Agricultural sustainability in India faces serious difficulties due to weather unpredictability, recurring crop fires, wild animal invasions, and inadequate water management. Krishi Prahari was created and constructed as an integrated, data-driven response to these difficulties delivering a single platform for threat detection, predictive decision-making, and automated action leveraging low-cost hardware and intelligent algorithms.

The system combines the capabilities of Internet of Things (IoT) sensors and Machine Learning (ML) models to deliver real-time environmental monitoring, early warning messages, and precision irrigation. Through field deployment and testing, Krishi Prahari displayed outstanding sensor accuracy (fire detection: 96.4%, wildlife detection: 94.1%) and consistent ML performance (F1-score: 0.93 for animal classification, irrigation MSE: 4.3%). These results demonstrate its skills to perform under real-world agricultural circumstances. Krishi Prahari modular architecture permits for scalability, while its solar-powered operation and wireless connection make it suited for off-grid and rural agricultural environments. Its user-friendly interface offered through internet and mobile platforms minimizes the technical learning curve and allows quick farmer adoption.

Moreover, comparative research indicated a 32% reduction in seasonal water usage, a 22% rise in average production per acre, and a significant reduction in reaction time to serious threats from almost 30 minutes to less than 5 seconds. These adjustments instantly lead to improved agricultural productivity, lower input costs, and enhanced food security.

In conclusion, Krishi Prahari is a realistic, cheap, and substantial smart agriculture solution. It bridges the technological barrier in rural farming and empowers producers with automation and data-driven insights. With future development such as drone integration, multi-language support, and AI-based pest identification it holds the potential to become a cornerstone in India’s agri-tech transformation and a repeatable model for sustainable farming internationally.

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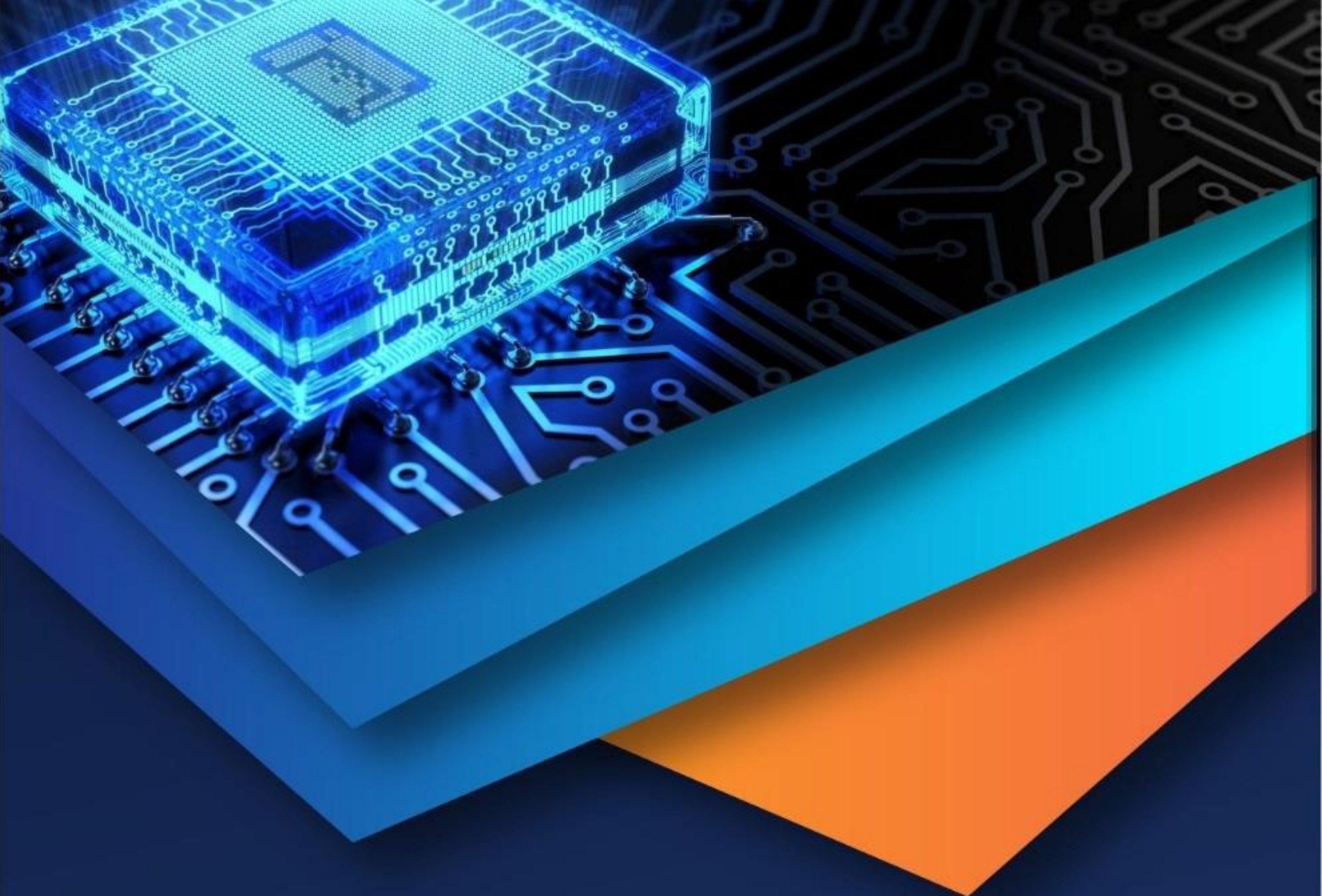

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