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Optimizing Grain Storage Using IoT: Reducing Post-Harvest Losses in Punjab

Abstract

Post-harvest grain losses remain a critical challenge in agricultural supply chains, particularly in regions like Punjab, which contribute significantly to national food security. This research proposes an advanced IoT-enabled system for optimizing grain storage conditions, integrating real-time environmental monitoring, predictive analytics, and automated control mechanisms. By employing a robust network of sensors, actuators, and communication protocols, combined with advanced data analytics and security measures, the system ensures optimal storage conditions while maintaining data integrity and minimizing operational costs.

Introduction

Agricultural post-harvest losses, particularly in grain storage, account for a substantial portion of global food wastage. In Punjab, where agriculture is the backbone of the economy, inefficient storage solutions lead to significant grain deterioration, primarily due to moisture, temperature fluctuations, and pest infestations. Traditional storage methods rely on periodic manual checks, which fail to provide the continuous monitoring and control necessary to prevent spoilage. IoT technologies offer a transformative approach, enabling the seamless integration of smart devices and automated systems to monitor, analyze, and optimize storage conditions in real time.

IoT System Architecture for Grain Storage

The proposed IoT system for grain storage comprises three core layers: the perception layer, the network layer, and the application layer.

Perception Layer

The perception layer encompasses all the physical devices that interact with the environment, including sensors and actuators. Temperature and humidity sensors form the core of the monitoring system, providing continuous data streams to track environmental conditions. Gas sensors, such as those detecting CO_2 and ammonia, enhance the system by identifying early signs of spoilage or pest activity. Actuators, including fans, dehumidifiers, and ventilation systems, respond automatically to deviations from optimal conditions, ensuring immediate corrective actions.

Network Layer

The network layer handles data transmission between IoT devices and the central processing system. It employs low-power, high-efficiency communication protocols to ensure seamless connectivity across the entire storage facility. lorawan is utilized for its long-range communication capabilities, particularly suited for rural storage units with limited connectivity. IEEE 802.15.4 provides a low-power wireless framework for intra-facility communication. IPv6 addressing via 6LoWPAN ensures scalability, allowing thousands of devices to operate within a unified network.

Application Layer

The application layer is responsible for data analysis, visualization, and user interaction. A centralized dashboard aggregates data from all connected devices, providing stakeholders with real-time insights into storage conditions. Machine learning algorithms process historical and real-time data to predict potential spoilage risks and recommend preventive measures. This layer also enables remote monitoring and control via mobile and web applications, enhancing accessibility and decision-making.

Communication Protocols and Data Management

Efficient data communication is vital for the seamless operation of the IoT system. The system employs a multi-tiered communication strategy to optimize data flow and ensure reliability.

Communication Protocols

- LoRaWAN facilitates long-distance communication, ensuring reliable data transmission from remote sensors to the central hub. Its low power consumption extends device battery life, reducing maintenance costs.

Data Processing and Storage

Data collected from sensors is processed locally using edge computing to minimize latency. Fog nodes at strategic locations perform preliminary analyses, filtering irrelevant data and sending only critical information to the cloud for deeper analysis and long-term storage. This hybrid approach balances processing efficiency and data accessibility, ensuring timely responses to environmental changes.

Predictive Analytics and Automation

Predictive Maintenance

Predictive analytics is central to the system's proactive approach to storage management. By analyzing historical data, machine learning models predict equipment failures and environmental anomalies, allowing for timely maintenance and preventing costly downtimes.

Automated Control Systems

The system's automation capabilities reduce human intervention by triggering actuators in response to sensor data. For example, if humidity levels exceed a preset threshold, the system automatically activates ventilation fans and dehumidifiers.

Security Framework

IoT systems in critical applications like grain storage require robust security to protect sensitive data and prevent unauthorized access.

Elliptic Curve Cryptography (ECC)

ECC provides lightweight, high-security encryption suitable for resource-constrained IoT devices. It ensures secure data exchange between sensors, actuators, and cloud servers, maintaining confidentiality and integrity.

Blockchain Integration

A private blockchain enhances data transparency and traceability. Every sensor reading and system action is recorded on the blockchain, creating an immutable ledger.

Cost Optimization Strategies

The system incorporates several cost-saving measures to enhance its economic feasibility:

Selective Deployment of Sensors: The system prioritizes essential sensors, such as those monitoring temperature and humidity, which have the most significant impact on grain preservation. Gas sensors are deployed selectively based on risk assessments, optimizing resource allocation.

- Energy-Efficient Protocols: lorawan and ieee 802.15.4 are chosen for their low power requirements, reducing energy consumption and extending device lifespan.
- Scalable Desig: The modular architecture allows incremental system expansion, enabling stakeholders to start small and scale up as needed, spreading out investment costs over time.

Conclusion

The proposed IoT-enabled grain storage system addresses the pressing issue of post-harvest losses in Punjab by providing a scalable, efficient, and cost-effective solution. Through real-time monitoring, predictive analytics, and automated controls, the system ensures optimal storage conditions, enhancing grain quality and reducing spoilage. Its robust security framework, leveraging ECC and blockchain, safeguards data integrity and fosters stakeholder trust. Cost optimization strategies further enhance its feasibility, making it accessible to a broad range of users. This research demonstrates the potential of IoT technologies to revolutionize grain storage, contributing to sustainable agricultural practices and improved food security.