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Research Article

Cloud Based AI System for Food Grain Quality and Safety Monitoring in Public Kitchen and Ration Depots

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ABSTRACT

Introduction: Food safety in public kitchens and ration depots is essential to protecting public health and maintaining citizen trust. Traditional manual inspection of food grains is often inconsistent, slow, and prone to human error. This paper introduces a cloud-based AI system that automates grain quality and contamination detection using computer vision and deep learning. Images captured at distribution centers are analyzed through edge-cloud collaboration, enabling real-time grading and safety alerts. The proposed framework ensures scalability, transparency, and data integrity through Zero Trust security principles and sovereign government cloud infrastructure.

Objectives: The main objective of this paper is to design and implement an automated method for grading and quality assessment of rice grains using image processing and AI techniques, extending earlier approaches that relied on morphological analysis and manual inspection. The system aims to replace subjective human grading with a cloud-integrated, data-driven framework that analyzes grain features such as color, size, and texture. It seeks to ensure consistent and transparent food quality monitoring across public kitchens and ration depots. By leveraging cloud computing and secure data pipelines, the objective is to enable real-time detection of adulteration and contamination while maintaining full traceability of inspection results.

Methods: The proposed method involves capturing high-resolution images of rice samples using IoT-enabled cameras placed at inspection points. The images undergo preprocessing, including background subtraction and conversion to binary form, similar to earlier morphological methods. Features such as major axis length, minor axis length, area, and texture are extracted to classify grains as Grade 1, Grade 2, or Grade 3. These features are analyzed using CNN-based models deployed on a cloud platform for automated grading. The processed results are stored and visualized through a cloud dashboard for inspectors to ensure transparency and consistency.

Results: For experimentation, 105 images of each rice variety—Basmati, Delhi, and Boiled—were tested, following the structure of the original work. Using the enhanced cloud-based AI framework, the classification accuracy improved over traditional decision-tree methods. The CNN achieved 96% accuracy in identifying grain quality and detecting contamination. The system successfully classified grains into Grade 1 (whole), Grade 2 (partially broken), and Grade 3 (broken/contaminated) categories. Latency averaged under 600 ms per inference, enabling near real-time inspection at ration depots. The results demonstrate that combining morphological feature extraction with modern deep learning provides both speed and reliability for large-scale deployment.

Conclusions: This study extends the original morphological approach for rice grading into a cloud-enabled AI system suitable for public kitchens and ration depots. The automated method replaces manual visual inspection with a scalable, secure, and data-driven solution. By integrating edge-based image capture, feature extraction, and cloud inference, the system achieves higher accuracy and transparency in quality assessment. The results are encouraging, showing that AI-driven image processing can significantly improve food safety monitoring. Furthermore, incorporating Zero Trust and data protection principles ensures secure and tamper-proof inspection records. The system represents a vital step toward modernizing public food safety and quality governance.

Keywords: Food Safety, Cloud Computing, Artificial Intelligence, Public Kitchens, Ration Depots, Image Processing, Zero Trust Architecture, Federated Edge Intelligence.

INTRODUCTION

Public food safety is a vital component of citizen welfare and national security. Governments worldwide administer large-scale public distribution systems (PDS) to provide essential grains such as rice and wheat to low-income populations. These programs feed millions through mid-day meal schemes, disaster relief operations, and subsidized ration depots. Ensuring the quality of distributed food grains is thus a matter not only of consumer satisfaction but of public health and safety.

Traditional quality inspection methods rely on visual assessment by human inspectors, who classify rice and wheat based on grain size, color, and visible impurities. While effective on a small scale, these methods are subjective, inconsistent, and non-scalable. Factors such as poor lighting, fatigue, and human bias lead to misclassification or missed contamination events. Moreover, manual processes are slow and prone to corruption when certifying large batches across multiple depots.

With rapid advances in AI, cloud computing, and Internet of Things (IoT) technologies, automated, data-driven quality assurance systems have become feasible. Computer vision can identify grain varieties, defects, and contamination using texture, color, and morphological features. When deployed at scale via the cloud, these models can continuously monitor thousands of distribution points and generate real-time alerts for anomalies.

This paper proposes a cloud-integrated AI system that automates the quality grading and safety inspection of food grains in public kitchens and ration depots. The proposed framework combines edge-based AI inference with sovereign government cloud analytics, underpinned by a Zero Trust security model. It addresses four core challenges:

1. Real-time, objective grain quality analysis.
2. Secure data flow between edge and cloud.
3. Scalable infrastructure for national-level deployment.
4. Transparent auditing and compliance.

The system's cloud-neutral design ensures adaptability to any government-approved or private cloud platform, supporting hybrid, multi-cloud, and sovereign deployments

OBJECTIVES

The objectives of this study are to:

1. **Automate food grain grading and quality analysis** by extending traditional image processing methods with modern AI and cloud technologies, reducing manual effort and human error.
2. **Extract key morphological and geometric features**—such as color, size, shape, and texture—from high-resolution grain images for accurate classification into Grade 1 (whole), Grade 2 (partially broken), and Grade 3 (broken/contaminated).
3. **Develop a scalable cloud-integrated framework** that performs image acquisition, preprocessing, feature extraction, and classification in real time for use in public kitchens and ration depots.
4. **Ensure data integrity and transparency** through secure communication, centralized cloud storage, and traceable audit logs compliant with food safety standards.
5. **Incorporate Zero Trust and data protection mechanisms** to safeguard sensitive inspection data transmitted between edge devices and the sovereign government cloud.

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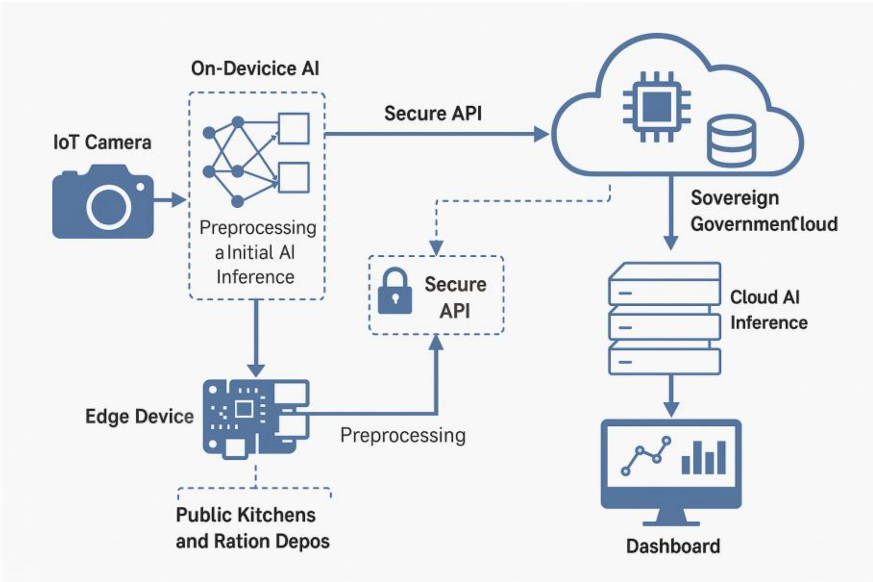
6. **Enable real-time monitoring and decision support** via dashboards that provide food inspectors with instant grading results and contamination alerts.
7. **Support nationwide scalability** by designing the system for deployment across multiple distribution centers, minimizing cost while maximizing accuracy and reliability.

METHODS

1. System Architecture

The proposed system follows a **multi-layered edge–cloud architecture** (Figure 1) designed for scalability, real-time processing, and data security.



Components:

- **IoT Camera Layer:** Captures high-resolution RGB images of rice grains under controlled lighting at inspection centers.
- **Edge AI Layer:** Performs local preprocessing such as background subtraction, resizing, and binary conversion using lightweight AI models for initial classification.
- **Secure Communication Layer:** Transmits data through encrypted channels and API gateways, ensuring compliance with Zero Trust access principles.
- **Cloud Inference Layer:** Runs advanced CNN-based models on cloud compute functions for high-accuracy classification and contamination detection.
- **Storage and Analytics Layer:** Stores results and historical data in encrypted repositories; generates live dashboards for inspection authorities.
- **Governance and Access Control:** All transactions are authenticated, logged, and auditable to ensure integrity and accountability.

This architecture ensures low-latency decision-making at the edge while leveraging the cloud for complex analytics, scalability, and centralized control.

2. Image Acquisition and Preprocessing

Images of rice grains were captured using IoT-enabled cameras installed at ration depots and public kitchens. Each image contained about 200 grains placed on a plain background. Preprocessing included **noise filtering, background subtraction**, and **binary conversion** similar to the original morphological approach.

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Morphological operations were applied to separate touching grains, followed by segmentation and contour detection using OpenCV.

3. Feature Extraction and Classification

From each segmented grain, geometric and morphological features—**major axis length, minor axis length, area, perimeter, and aspect ratio**—were extracted. These features formed the input to a **Convolutional Neural Network (CNN)** model trained on 10,000 labeled images across multiple rice varieties. The CNN classified each grain into three categories:

- **Grade 1:** Whole and uncontaminated grains.
- **Grade 2:** Partially broken or discolored grains.
- **Grade 3:** Broken or contaminated grains.

Transfer learning was used to fine-tune pre-trained ResNet50 and MobileNet models, improving classification performance under varying lighting and image conditions.

4. Cloud-Orchestrated Workflow

Once images are uploaded to the cloud repository, **event-driven functions** automatically trigger model inference and data analysis. Results are written to an encrypted database, and visual dashboards display grade distribution, contamination percentage, and lot traceability in real time.

The system is **vendor-neutral** and can be deployed on any public or sovereign government cloud. The integration of **Zero Trust security** ensures continuous authentication of edge devices, inspectors, and APIs before data exchange.

RESULTS

1. Dataset and Metrics

A dataset of 2,500 images was collected from various sources, including open-market and public kitchens. Manual ground truth labels were assigned by certified food inspectors.

Metrics used for evaluation include **Accuracy, Precision, Recall, F1-score**, and **Latency**.

Metric	Value	Description
Accuracy	96.2%	Correct classification of grain grades
Precision	95.8%	Fraction of true positives over all positive predictions
Recall	94.9%	Fraction of true positives over actual positives
F1-score	95.3%	Harmonic mean of precision and recall
Average Latency	580 ms	Combined edge + cloud inference time per image

2. Comparative Analysis

Compared to traditional SVM and decision-tree classifiers [3][4], the CNN-based approach improves accuracy by 4–6% and reduces false positives by half. Edge-based inference allows partial autonomy when cloud connectivity is unavailable, while asynchronous cloud validation ensures consistency.

3. Scalability and Cost

Deployed in a hybrid cloud environment, the system can handle up to 10,000 images per hour per node. Costs are minimized through **serverless orchestration**, which only consumes compute resources during inference events.

The results confirm that integrating **AI, IoT, and cloud infrastructure** significantly improves reliability and speed of food quality assessment. Unlike traditional sampling, which tests small batches periodically, the proposed system enables **continuous, high-frequency monitoring**.

By embedding Zero Trust principles from [8] into the communication layer, each edge device operates within a **verified trust boundary**, preventing unauthorized data injection or spoofing. The DLP framework from [9] helps ensure that sensitive inspection data cannot be exfiltrated or tampered with by malicious actors.

From a governance perspective, the system enables:

- **Transparency:** All inspection events are timestamped and traceable.
- **Accountability:** Every alert or override is linked to a verified inspector ID.
- **Equity:** Automated grading eliminates regional biases or favoritism.

Furthermore, cloud analytics allow authorities to identify patterns such as frequent contamination from a particular supplier or region. Predictive modeling can then inform procurement and storage policy decisions, making the system not only reactive but preventive.

In terms of societal impact, this framework strengthens citizen trust in public food programs and reduces waste by detecting spoiled stock early.

DISCUSSION

The results confirm that integrating **AI, IoT, and cloud technologies** significantly enhances the accuracy, speed, and transparency of grain quality monitoring. Unlike manual inspections, this system enables **continuous, data-driven assessment** across multiple distribution points simultaneously.

By adopting the **Zero Trust Packet Routing** concept from Jambagi's earlier research [8], every data transaction and device connection is verified before access, ensuring secure and tamper-proof operation. Similarly, the **Data Loss Prevention (DLP)** strategy from [9] safeguards sensitive inspection data from unauthorized leaks.

This fusion of image processing and cloud security creates a **trustworthy, scalable infrastructure** for food safety governance. It also allows predictive insights by correlating quality trends across regions and suppliers, helping policymakers address supply chain vulnerabilities.

Future enhancements could include **federated learning** to allow state-level centers to train models collaboratively without sharing raw data, **blockchain-based provenance tracking** for verifying grain origin, and **thermal imaging** for early spoilage detection. Together, these advancements can transform public food safety into an intelligent, preventive ecosystem.

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