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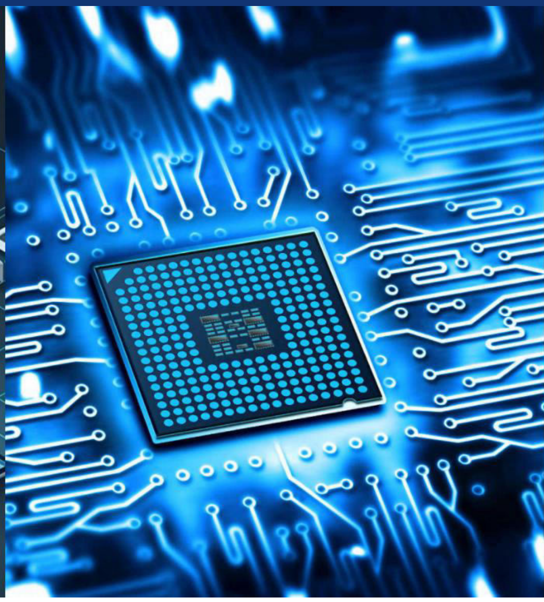


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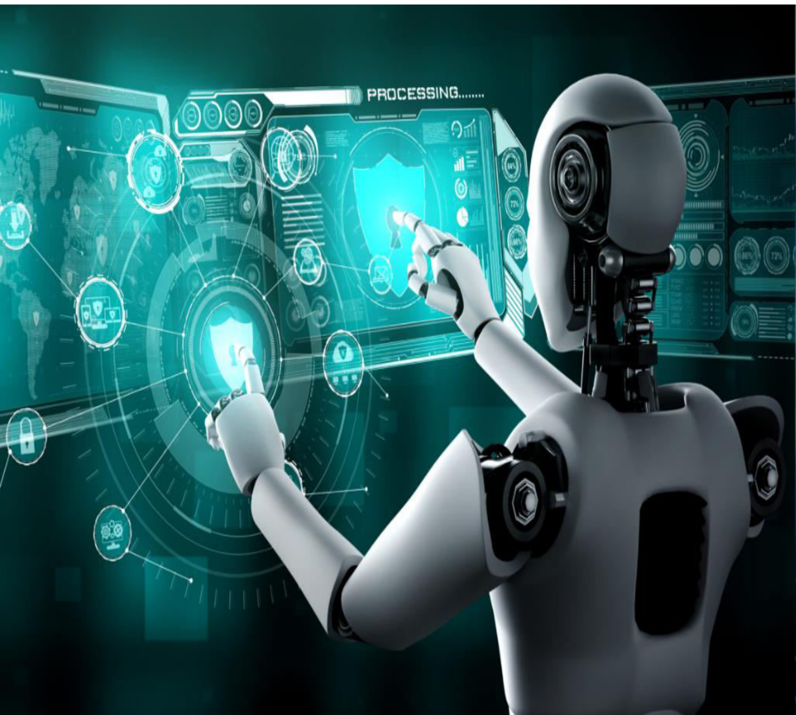

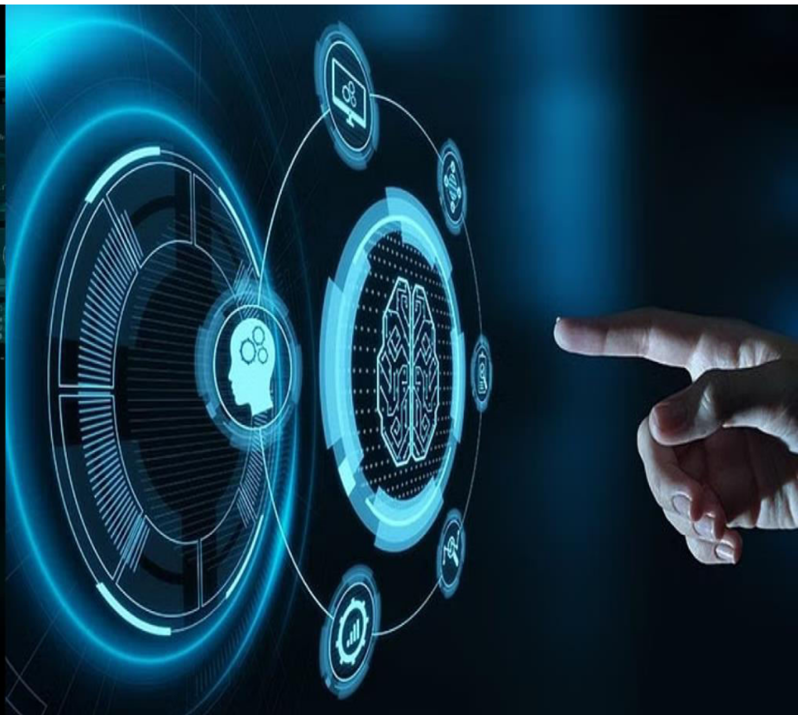

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ReHarvest.AI: A Multimodal Deep Learning and Smart Routing Framework for Sustainable Fruit Waste Reduction

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ABSTRACT: Fruit waste in the supply chain is a major sustainability challenge, leading to economic loss and environmental impact. This paper presents ReHarvest.AI, an intelligent system designed to reduce fruit waste using deep learning and smart logistics. The system employs a Convolutional Neural Network (CNN) to classify fruits into freshness stages such as fresh, near spoilage, and spoiled. It also predicts shelf life using environmental data to support timely decision-making. Based on these insights, a smart routing module directs edible fruits to NGOs for donation, while spoiled fruits are sent for composting or biogas production. The platform integrates real-time inventory tracking, automated alerts, and role-based dashboards for efficient coordination. Experimental results show improved spoilage detection accuracy and reduced waste through optimized redistribution. The proposed system enhances sustainable supply chain management by combining AI, analytics, and collaborative logistics.

KEYWORDS: Fruit Waste Reduction, Artificial Intelligence, Spoilage Classification, Predictive Analytics, Smart Supply Chain, Waste-to-Resource, Real-Time Monitoring.

I. INTRODUCTION

Fruit waste in the supply chain is a major global challenge, causing economic loss, environmental damage, and food insecurity. A significant amount of fruit is wasted due to improper handling, delayed spoilage detection, and inefficient redistribution. Traditional methods rely on manual inspection, which is often slow and inaccurate, highlighting the need for intelligent, data-driven solutions.

ReHarvest.AI is an AI-based platform designed to reduce fruit waste using deep learning and smart logistics. It classifies fruits into freshness categories—fresh, near spoilage, and spoiled—using image processing techniques, and predicts shelf life based on environmental conditions. The system includes a smart routing mechanism that redistributes consumable fruits to NGOs and directs spoiled fruits for composting or biogas production.

Additionally, the platform provides real-time tracking, alerts, and dashboards for stakeholders, ensuring efficient coordination. By integrating AI, analytics, and automation, ReHarvest.AI supports sustainable fruit waste management and resource optimization.

II. RELATED WORK

Recent advancements in artificial intelligence, computer vision, and smart logistics have enabled efficient solutions for fruit waste reduction. AI-based classification systems, particularly Convolutional Neural Networks (CNNs), have shown high accuracy in identifying fruit freshness and spoilage levels. Models such as VGG-19 and similar architectures are widely used for automated waste classification based on visual features.

In addition, research on reverse logistics focuses on optimizing the redistribution of perishable goods using real-time data such as inventory status and shelf-life prediction. Dynamic routing systems help minimize waste by directing consumable fruits to donation channels and diverting spoiled items to composting or energy recovery.

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Real-time monitoring systems and mobile applications further support waste reduction by providing spoilage detection, ripeness estimation, and timely alerts. However, most existing solutions address these components independently.

ReHarvest.AI integrates classification, predictive analytics, and smart routing into a unified platform, offering a comprehensive and scalable solution for sustainable fruit waste management.

III. PROPOSED ALGORITHM

The proposed ReHarvest.AI system manages fruit waste using machine learning, image processing, and smart routing. It classifies fruits based on spoilage levels, predicts shelf life using environmental data, and enables automated decision-making for efficient utilization.

The system consists of key modules including image acquisition, spoilage detection, shelf-life prediction, smart routing, and cloud-based data management, working together to support real-time monitoring and optimized redistribution.

3.1 Image Acquisition and Pre-Processing

The first stage of the system involves capturing fruit images through a mobile or web interface by shopkeepers or collectors. The captured image is preprocessed before being passed to the machine learning model.

The preprocessing stage includes:
* Converting the image to RGB format
* Resizing the image to 224 × 224 pixels
* Normalizing pixel values for improved model performance

The processed image is then converted into tensor format suitable for CNN inference.

$Ip = Normaliz(Resize(I, 224 \times 224))$

Where:

I = input fruit image,Ip = processed image

This step ensures uniformity and consistency across all input images.

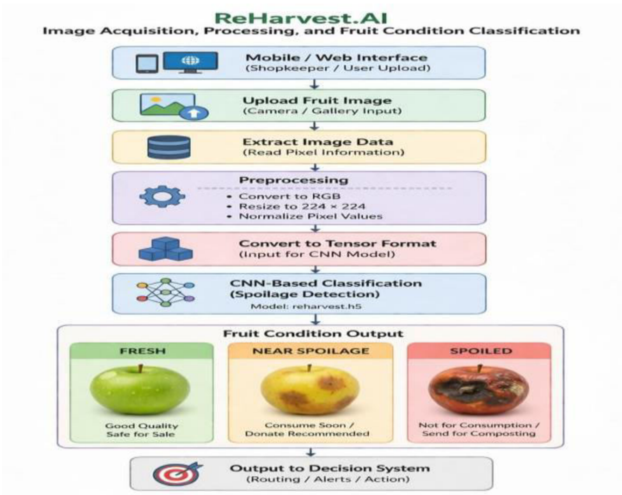

Fig. 3.1.1. Image Acquisition and CNN-Based Spoilage Detection Workflow

3.2 CNN-Based Spoilage Detection

After preprocessing, the image is passed to a trained Convolutional Neural Network (CNN) model (reharvest.h5). The model extracts visual features such as texture, color variation, and surface defects to classify fruit condition.

The output is a probability vector indicating the likelihood of each class:
* Fresh
* Near Spoilage

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* Spoiled
The final classification is obtained by selecting the class with the highest probability.
C=arg max(CNN(Ip))
Where:
CNN = trained deep learning model
C = predicted fruit condition
The model also generates a confidence score indicating prediction reliability.

3.3 Shelf-Life Prediction and Environmental Analysis
To enhance decision-making, the system integrates environmental and temporal data to estimate the remaining shelf life of fruits.
The parameters considered include:
* Temperature
* Humidity
* Storage duration
These factors are used to compute the spoilage risk and remaining usable time.
$S=f(T,H,t)$
Where:
T = temperature
H = humidity
t = storage time
S = estimated shelf life
This module enables proactive identification of fruits that are likely to spoil soon.

3.4 AI-Based Decision and Routing Mechanism
Based on the classification and shelf-life prediction, the system determines the optimal action using a rule-based decision engine.
* If fruit is Fresh → Retain for sale
* If Near Spoilage and shelf-life below threshold → Route for donation
* If Spoiled → Route for composting or biogas production
The smart routing system then assigns the appropriate destination by analyzing:
* Distance to NGOs or compost units
* Availability of collectors
* Urgency based on spoilage level
This ensures efficient and timely redistribution of fruits.

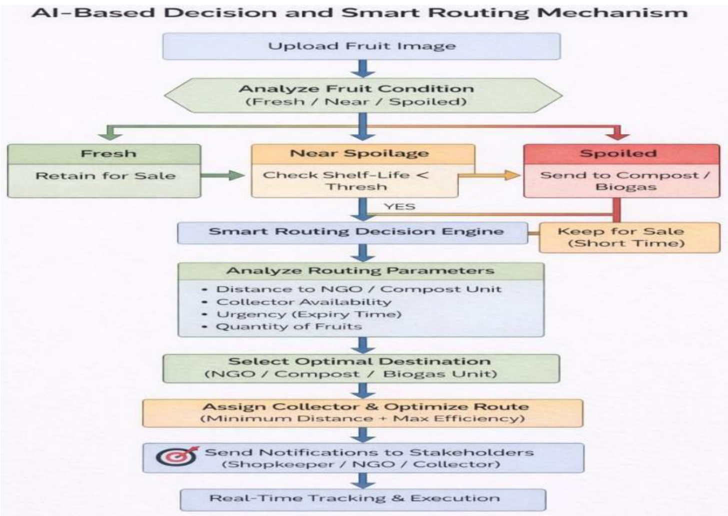

Fig. 3.4.1: Smart routing and decision-making workflow for fruit waste management in ReHarvest.AI.

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3.5 Cloud Data Management and Dashboard Integration

All system data, including predictions, inventory, and routing logs, are stored in a cloud database. The dashboard provides waste statistics, donation metrics, real-time tracking, and environmental impact analysis, enabling stakeholders to monitor performance and make data-driven decisions

3.6 Pseudocode of Proposed Algorithm

1. Initialize system and load CNN model
2. Capture or upload fruit image
3. Preprocess image (resize, normalize)
4. Classify fruit condition using CNN
5. Collect environmental data (temperature, humidity, time)
6. Estimate shelf life
7. Make decision (store, donate, or compost)
8. Optimize routing and assign collector
9. Store results in database
10. Display output on dashboard

IV. SIMULATION RESULTS

The ReHarvest.AI system was evaluated through functional testing of the web-based prototype. The results show effective fruit classification, smart routing, and stakeholder interaction through a user-friendly interface.

The system integrates waste logging, freshness assessment, routing decisions, and logistics coordination, enabling efficient handling of fruit waste and timely actions by all stakeholders.

Fig.4.1. Reharvest.AI system login page

The admin module provides an overview of system performance, including waste handling, donation activity, delivery status, and environmental impact. It also offers weekly trends and pickup tracking, helping administrators monitor operations and make informed decisions.

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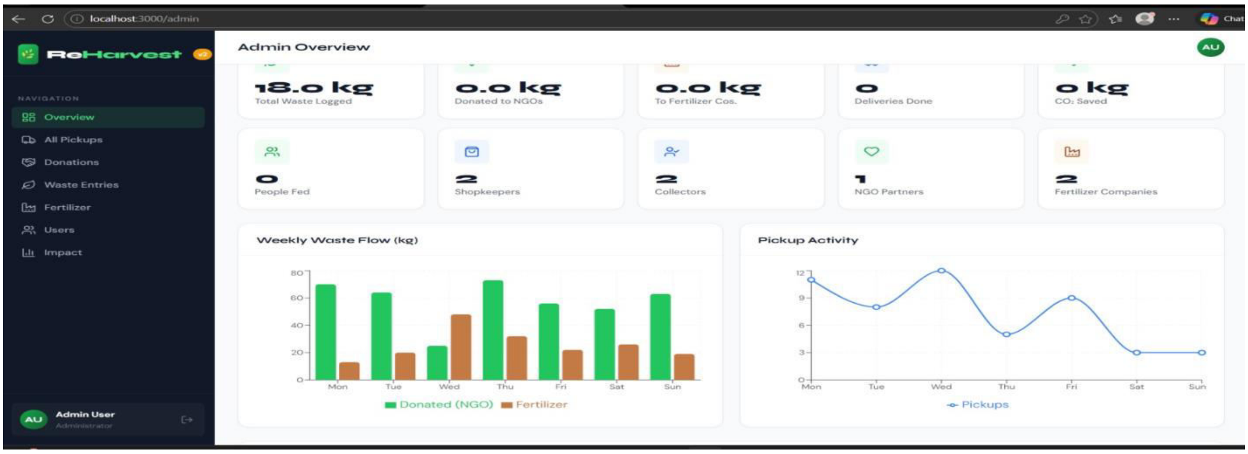

Fig.4.2. Admin dashboard overview

The shopkeeper module enables users to log fruit waste and classify it as fresh, near spoilage, or spoiled. Based on this, the system suggests appropriate actions such as donation or composting. It also includes a reward mechanism to encourage responsible participation.

Fig.4.6. Fertilizer processing dashboard.

V. CONCLUSION AND FUTURE SCOPE

ReHarvest.AI provides an intelligent solution for fruit waste management by integrating AI-based spoilage detection, predictive analytics, and smart routing. The system classifies fruits based on freshness, supports timely decision-making, and improves resource utilization through real-time tracking and dashboards. Its cloud-based and modular design ensures efficient coordination among stakeholders while promoting sustainability through waste reduction and food redistribution.

Future improvements include using larger datasets, integrating IoT sensors for better shelf-life prediction, and enhancing routing with advanced machine learning techniques. Expanding to mobile platforms, adding multilingual support, and integrating with broader distribution systems can further increase its scalability and real-world impact.

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