



IoT-Enabled Multi-Modal AI System for Detecting and Predicting the Freshness and Ripeness of Produce

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Accurate evaluation of the quality of produce is essential for food safety, consumer acceptance, and reduction of post-harvest losses. Manual inspection and chemical tests, which are considered traditional methods, are subjective, tedious, and destructive. The proposed approach is a Multi-Modal AI System that detects and predicts the freshness and ripeness of produce through a non-destructive intelligent system, helping to overcome these limitations. The methodology employs a two-stage hierarchical pipeline that integrates visual information from a camera module with data from a sensor array comprising MQ4 (methane), MQ135 (CO₂/ammonia), TGS2602 (Volatile Organic Compounds), and an AS7263 Near-Infrared (NIR) spectrometer. In Stage 1, an object detection model identifies the type of produce. In Stage 2, visual features extracted by a Convolutional Neural Network (CNN) are combined with normalized sensor-array readings in a novel early fusion model to determine freshness and ripeness. The findings clearly demonstrate the strength of data fusion, with the multi-modal framework achieving an overall prediction accuracy of 95%. This approach outperformed the unimodal methods, which achieved accuracies of 93% for image-only and 88% for sensor-only data, respectively. Additionally, the Vision Transformer (ViT) model, designed specifically to detect artificially ripened fruit, achieved accuracies of 94% for bananas and 92% for mangoes. The system is deployed through three applications, including a “GreenMate” physical device, an “AI Food Assistant” mobile application, and a standalone portable device specifically designed for the classification of artificial ripening in mangoes and bananas. Together, these solutions provide a low-cost, real-time, and practical approach to enhancing supply chain transparency, protecting consumers, and reducing food waste.

Keywords: Multi-Modal AI System, Freshness and Ripeness Prediction, Data Fusion, Computer Vision