**Hyperspectral Imaging-Based Automated Apple Quality Assessment**

A Project Report

submitted in partial fulfilment of the requirement for the Degree of Bachelor of Information Technology

Maulana Abul Kalam Azad University of Technology, West Bengal December-2023

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**ABSTRACT –**

Hyperspectral imaging has advanced significantly in the past decade, becoming a crucial tool for nondestructive quality assessment of fruits and vegetables by integrating imaging and spectroscopy to capture monochromatic images across a wide range of wavelengths. This technique addresses the increasing consumer demand for diverse fruit and vegetable attributes like ripeness, size, and color, as well as internal properties.

In normal visible range or any human eye can not detect the defects inside the healty parts of any food item, such like in apple (bruising, Crispness, Ripeness, Acidity, vitamin and antioxidants, Sweetness), in visible range we can only see the texture, color, Size and shape.

Also, Traditional computer vision systems struggle with detecting defects that resemble healthy parts, but hyperspectral and multispectral imaging can differentiate and detect such defects. Research highlights include hyperspectral imaging for bruise detection, multispectral analysis for food classification, and various spectroscopic methods for determining food quality.

The proposed methodology involves acquiring hyperspectral data and multispectral images using a Raspberry Pi with RGB and IR cameras, performing calibration and normalization, aligning multispectral with hyperspectral data, and training a deep learning model for image conversion. The integrated system will assess apple quality in real-time by extracting features from hyperspectral data and using a classification model.

**1.INTRODUCTION-**

In recent years, consumer demand for fruits and vegetables tends to be diversified, and more attention has been paid to the external quality of apples. Generally, such attributes include its ripeness, size, weight, shape, color, condition, or presence/absence of defects, stems or seeds, as well as a series of internal properties such as sweetness, acidity, texture, hardness, among others . Consequently, the accurate, rapid, and objective assessment system in the processing stage is essential to ensure the quality of fruits and vegetables during processing operations. Food process control necessitates real-time monitoring at critical processing points.

Over the past decades, with the rapid development of information science, image processing and pattern recognition technology, optical sensing technologies have been emerged as scientific tools for nondestructive assessment for quality of fruits and vegetables. Spectral imaging technology, combining conventional imaging and spectroscopy techniques, can acquire spatial and spectral information from the target, which is used for evaluating individual food products. In particular, hyperspectral imaging has been widely researched and developed by integrating spectroscopy and imaging techniques into a system that can obtain a spatial map of spectral variation, resulting in many successful applications in the quality assessment of fruits and vegetables. A typical spectral image is composed of a set of monochromatic images corresponding to certain wavelengths, and hyperspectral image systems have the natural advantage compared to the traditional computer vision, even the human vision. Hyperspectral imaging systems can make it possible to extract some appearance features that are difficult or impossible with the traditional computer vision systems.

**2. LITERATURE SURVEY**

Due to lack of spectral information in conventional color images, traditional computer vision system is not efficient for the inspection of some defects with similar color and texture as sound peel, such as bruises, rottenness, or chilling injury.

Hyperspectral and multispectral imaging systems provide powerful tools not only to detect skin defects but also to differentiate between a variety of defects that have similar color and texture or even to detect some defects that are not clearly visible.

Bruising is one of the familiar defects occurring on fruits and vegetables during post-harvest handling and processing stage. The existing commercial sorting machines are still not available in detecting bruises.

-An experiment of using a hyperspectral imaging system for bruise detection on apples was conducted by Xing et al.

The present study was motivated by such a multi-spectral approach, and the procedure for food classification and caloric estimation adopted a multi-spectral analysis technique.

- Multispectral Food Classification and Caloric Estimation Using Convolutional Neural Networks by Ki-Seung Lee

The study of food authenticity involves establishing whether a sample is genuine in terms of its description, including geographical origin.

- Determination of Food Quality by Using Spectroscopic Methods, WRITTEN BY - Agnieszka Nawrocka and Joanna Lamorska

**UV–visible spectroscopy** uses electromagnetic radiation in the range 100–750 nm. The UV range covers 100–380 nm and the visible range covers 380–750 nm.31 It detects two different aspects: (1) colour and (2) fat oxidation. In oils, the greater the carotenoid (a pigment or chromophore such as chlorophyll, which most plants contain) content, the better is the antioxidant activity. The presence of chlorophyll makes olive oil bitter.

-Spectroscopic Techniques for the Analysis of Food Quality, Chemistry, and Function, Written by-Monalisa Mishra

**Fluorescence spectroscopy** is a rapid means to analyse a sample in a non-destructive way. It detects the fluorescence based on a naturally present fluorophore within the sample.45 Many microbes and their colonies possess fluorescence, hence it is easy to detect the presence of any microbes based on their fluorescence spectra. Many foods possess fluorophores. There is also a chance that food may become contaminated due to the presence of microbes.

-Meat and seafood lose their quality owing to oxidation, autolysis of enzymes, and growth of microbes. All these phenomena can be detected by monitoring the fluorophores present within the sample. Meat possesses fluorophores such as tryptophan, nicotinamide adenine dinucleotide (NA DH), porphyrins, riboflavin, and vitamin A.

**Infrared Spectroscopy** Infrared (IR) radiation was discovered in 1800 by William Herschel.86 Its range varies between 78 nm and 1 mm. This technique uses the vibration of atoms and molecules. Different vibrations were observed in the IR region. IR spectra provide evidence of molecular structure from the frequency of the normal mode of vibration. In the case of the normal modes, the sample executes harmonic oscillations. There are six normal modes. The vibrations of functional groups such as OH, NH2, CH3, and C=O are responsible for bands near the IR spectrum. Any compound containing a C=O group shows strong bands at 1899 and 1650 cm−1. The NH2 group gives an IR band between 3400 and 3300cm−1.A compound with a C6H5 group gives peaks at 1600 and 1500 cm−1.Thus the IR spectrum is considered as the fingerprint of the molecule. Based on the range, it is divided into three forms: (1) near-infrared(780 nm–5 μm),(2) mid-infrared (5–30 μm), and (3) far-infrared(30–1000 μm).

**Near-infrared (NIR) spectroscopy** has been primarily employed in the quantitative analysis of foods. The spectroscopy has been applied to measure moisture, fat, protein and carbohydrate content in wide variety of foods. The most significant advantage is its ability to determine simultaneously several components in a food sample within a short time. The precision of NIR analysis for a wide range of applications is comparable to or better than that of the chemical techniques it replaces. On the other hand, the main disadvantage of NIR quantitative analysis is that it requires calibration using samples of known composition. This has seriously limited the use of NIR spectroscopy because of the large amount of time and expense required for the development of calibrations. This disadvantage is compounded by the problem of calibration instability resulting from changes in sample or instrument characteristics over time, which can make frequent recalibration necessary, and the lack of transferability of calibrations owing to optical differences between instruments. Other disadvantages of NIR analysis include the need for high-precision spectroscopic instruments, the complexity of data treatment, and the lack of sensitivity for minor constituents.

**-** Determination of Food Quality by Using Spectroscopic Methods, WRITTEN BY Agnieszka Nawrocka and Joanna Lamorska

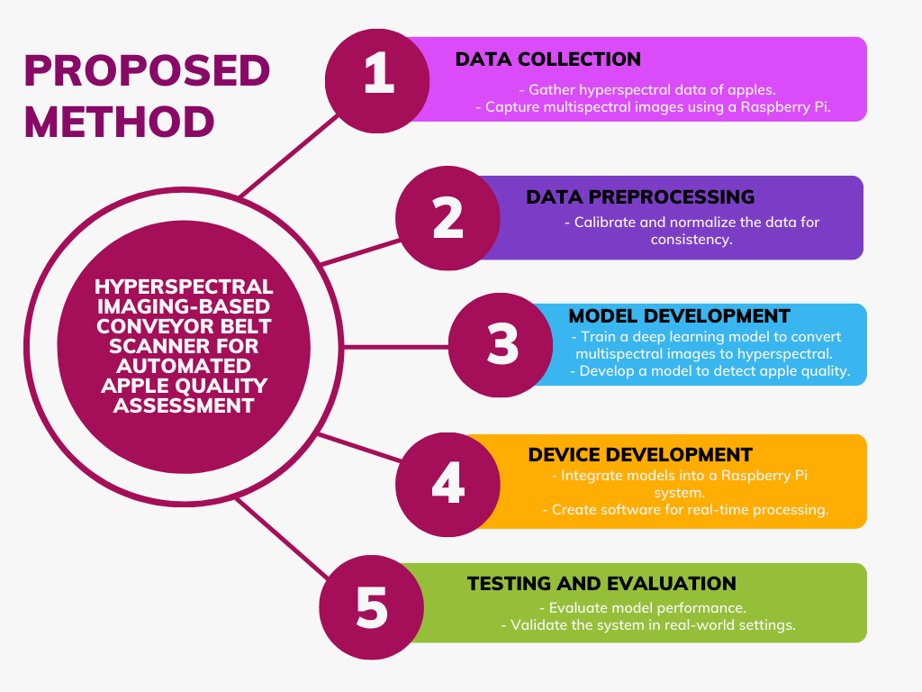
**Far-infrared spectroscopy-**The region below 400 cm-1 down to 10 cm-1 is defined as the far-infrared. The region below 200 cm-1 is not readily accessible and there are not many useful spectra-structure correlations in this region. However, compounds containing halogen atoms, organometallic compounds and inorganic compounds absorb in the far-infrared and torsional vibrations and hydrogen bond stretching modes are found in this region

- Shurvell, H.F. Spectra-structure correlations in the mid- and far-infrared. Handbook of Vibrational Spectroscopy 2006

**Raman Spectroscopy** When photons interact with molecules in matter the Raman effect or Raman scattering is produced. During this process, the photon loses vibrational energy in the Stokes process and gains vibrational energy in the anti-Stokes process. Such communication is possible for the interactions of atoms, which moderate the polarizability of the molecule. Such communication is possible for the cross-talk of incident photons with atoms. Intense Raman bands are detected from non-polar groups, predominantly from aromatic rings, and the vibrations produce an inflection of polarizability. The Raman spectrum is obtained as wavenumbers (cm−1) and the variation between excited and emitted energies is detected as vibrational spectra.

-The limitations of the technique must also be considered. First of all, the probability of Raman scattering is very low, so the effect is weak and high concentrations of samples are required. Secondly, in Raman experiments excitation within the electronic absorption band often causes photodegradation of the molecule. To avoid such problems, low laser powers, moving samples and independent inspection of the sample integrity are often employed. Finally, many molecules, or impurities in the sample, exhibit intense fluorescence, obscuring the Raman spectra

- Niaura, G. Raman spectroscopy in analysis of biomolecules. Encyclopedia of Analytical Chemistry 2008.

**3.PROPOSED METHODOLOGY**

**1. Data Collection**

* + - Hyperspectral Data Acquisition: Collect hyperspectral data of apples from the Geological Survey of India (GSI) or other available sources to serve as ground truth.
    - Multispectral Image Capture: Use a Raspberry Pi equipped with an RGB and IR camera to capture multispectral images of apples.

2. **Data Preprocessing**

* + - Calibration: Perform radiometric calibration on both multispectral and hyperspectral images.
    - Normalization: Normalize the data to ensure consistency and account for lighting variations.

3. **Model Development for Image Conversion**

* + - Data Alignment: Align the collected multispectral images with the corresponding hyperspectral data.
    - Deep Learning Model: Develop and train a deep learning model (e.g., a Convolutional Neural Network (CNN) or Generative Adversarial Network (GAN)) to convert multispectral images into hyperspectral images.
    - Training Process: Use the aligned dataset to train the model, minimizing the difference between predicted and actual hyperspectral data using suitable loss functions and optimization techniques.

4. **Development of Raspberry Pi-Based Device**

* Hardware Integration: Integrate the trained deep learning model into a Raspberry Pi-based system equipped with an IR and RGB camera for real-time scanning of apples on a conveyor belt.
* Software Setup: Develop software to process the captured multispectral images, convert them to hyperspectral images, and extract relevant features.

5. **Model Development for Quality Detection**

* Feature Extraction: Use the converted hyperspectral data to extract features related to apple quality.
* Spectral Indices: Calculate spectral indices that correlate with quality parameters such as ripeness, contamination, and defects.
* Quality Classification Model: Develop a second AI model to classify apples based on the extracted features into quality levels (e.g., fresh, slightly fresh, not fresh).
* Training: Train the classification model using labeled quality data and the extracted features.

6. **System Integration and Real-Time Processing**

* Real-Time Quality Assessment: Implement the quality detection model into the Raspberry Pi system for real-time apple quality assessment.
* User Interface: Create an interface to display the quality assessment results to users in real-time.

7. **Evaluation and Testing**

* Performance Metrics: Evaluate the performance of both the image conversion and quality detection models using metrics like Mean Squared Error (MSE), accuracy, precision, recall, and F1-score.
* Cross-Validation: Perform cross-validation to ensure robustness and reliability of the models.
* Field Testing: Validate the integrated system in real-world industrial settings and refine the models based on feedback.

By following these steps, the project aims to develop an efficient and accurate hyperspectral imaging-based automated apple quality assessment.

**4. FUTURE SCOPE:**

Future research should focus on addressing these challenges to enhance the applicability of HSI and ML in the food industry. Key areas include:

* Cost Reduction: Developing low-cost materials and devices for HSI systems to make them more accessible for industrial applications .
* Advanced Algorithms: Utilizing advanced ML algorithms, such as lifelong learning and reinforcement learning, to improve model accuracy and efficiency. These algorithms can continuously learn from new data, similar to human learning processes .
* Integration of Spectral and Spatial Data: Combining spectral and spatial data at the pixel level to improve classification accuracy. This approach can provide a more holistic understanding of food quality attributes .

**5. CONCLUSION:**

In conclusion, by integrating Raspberry Pi with hyperspectral imaging technology, we can develop a versatile, cost-effective, and portable system for real-time food quality and safety assessment. This innovative approach has the potential to revolutionize quality control processes in the food industry, ensuring safer and higher-quality food products for consumers. With its ability to provide detailed information about food composition and detect various quality parameters, such as ripeness, contamination, and defects, this system offers a practical solution for improving food quality assurance practices.

Furthermore, its scalability and adaptability make it suitable for a wide range of food products beyond apples, promising broader applications in the food industry. Overall, this project represents a significant step forward in enhancing food safety and quality standards.

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