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Importance of Machine Vision Framework with Nondestructive Approach for Fruit Classification and Grading: A Review

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Abstract— Machine vision technology has gained significant importance in the agricultural industry, particularly in the non-destructive classification and grading of fruits. This paper presents a comprehensive review of the existing literature, highlighting the crucial role of machine vision in automating the fruit quality assessment process. The study encompasses various aspects, including image acquisition techniques, feature extraction methods, and classification algorithms. The analysis reveals the substantial progress made in the field, such as developing sophisticated hardware and software solutions, which have improved accuracy and efficiency in fruit grading. Furthermore, it discusses the challenges and limitations, such as dealing with variability in fruit appearance, handling different fruit types, and real-time processing. The identification of future research needs emphasizes the potential for enhancing machine vision frameworks through the integration of advanced technologies like deep learning and artificial intelligence.Additionally, it underscores the importance of addressing the specific needs of different fruit varieties and exploring the applicability of machine vision in real-world scenarios, such as fruit packaging and logistics. This review underscores the critical role of machine vision in non-destructive fruit classification and grading, with numerous opportunities for further research and innovation. As the agricultural industry continues to evolve, integrating machine vision technologies will be instrumental in improving fruit quality assessment, reducing food waste, and enhancing the overall efficiency of fruit processing and distribution.

Keywords- Non-destructive, Near-infrared, quality grading, machine learning

I. Introduction

Mango (Mangifera indica) is one of the most popular and economically significant tropical fruits globally. Among the numerous mango cultivars, 'Keitt' stands out for its exceptional flavor, nutritional value, and export potential [1]. However, the occurrence of internal physiological disorders, such as chilling injury, internal breakdown, and flesh browning, poses a significant challenge to both growers and consumers. These disorders are often hidden from external inspection and only become evident after harvest, causing post-harvest losses and diminishing fruit quality. Traditionally, the evaluation of mango peel color and pigment content has been performed through destructive methods that involve peeling the fruit or extracting pigments. These methods are not only time-consuming but also result in fruit wastage, making them less practical for large-scale quality assessment in the industry. Non- destructive technologies, particularly spectroscopy and imaging, present a promising alternative. Spectroscopy entails the exposure of mango peel to light across the electromagnetic spectrum,

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capturing the wavelengths of light absorbed, transmitted, or reflected by the peel. The resulting spectral data can yield valuable insights into the color and pigment composition of the peel without physically altering the fruit. This study unites non-destructive techniques such as spectroscopy and imaging with advanced data analysis and modeling, leading to the development of reliable and swift methods for predicting color and pigment contents in mango peel. The outcomes of this research could revolutionize mango quality assessment practices, curbing waste and ensuring the steady delivery of high-quality mangoes to growers, processors, distributors, and consumers. As the global demand for fresh, nutritious produce continues to surge, the capability to non-destructively forecast color and pigment contents in mango peel promises to make a substantial impact on the success and competitiveness of the mango industry.

The recognition of color is a crucial parameter for evaluating the external quality of mangoes. It involves assessing the appearance and surface of mango fruits based on their skin or outer surface. Visual inspection is a straightforward method, with variations mainly depending on changes in lighting and illumination. However, traditional color measurement methods have limitations, even though basic color information can be directly obtained from image datasets. Standard color measurement typically assumes a uniform and consistent surface. When the surface of an object has multiple colors or is non-uniform, measures must be repeated several times to capture the color variations accurately. In cases where the surface area of the thing, such as a mango, exhibits diverse colors, estimating the color becomes a challenging task, especially when dealing with a large volume of fruits with non-homogeneous characteristics [2]. As a result, there is a pressing need to develop rapid and non-destructive methods for accurate color estimation, particularly for assessing the color distribution in agricultural products. Such advancements in color measurement techniques are crucial for improving the precision and efficiency of evaluating the external quality of fruits like mangoes in agricultural production.

Disease assessment is another critical parameter in evaluating the external quality of mango fruits. Common diseases that affect mango fruits include over-ripeness and bruises. While mango deterioration is inevitable, non-destructive methods provide a solution for assessing external characteristics to detect various types of defects during the handling and processing of mangoes. Identifying superficial weaknesses is vital, as it can significantly impact the quality and market value of mango fruits [3]. However, grading mangoes based on their external parameters presents challenges due to several factors. Mango fruits exhibit variations in illumination, shape, and ripeness conditions. These variations make it difficult to establish a consistent and accurate grading system solely based on external features. Therefore, developing effective non-destructive techniques for disease and defect detection in mangoes is essential to ensure the quality and marketability of these fruits while streamlining the sorting and handling processes.

II. Internal quality parameters for mango

Consumer preferences for agricultural products are influenced by various factors, with quality and cost being primary considerations. The internal attributes mentioned, such as Total Acidity (TA), Dryness, Firmness, Maturity, and Un-maturity, play a crucial role in determining the overall quality of agricultural products, including mangoes. Let's briefly discuss these attributes: Total Acidity (TA), Total Acidity (TA), Firmness, and Maturity. To address this challenge, consumers can learn to select mangoes based on visual and tactile cues, such as color and firmness. Additionally, sellers can provide information about the expected ripening time for the mangoes they sell, helping consumers make more informed choices [4]. In summary, understanding the internal attributes of agricultural products like mangoes is essential for consumers and sellers to make informed decisions about quality and ripeness. Still, the dynamic nature of these attributes due to ripening makes it necessary to develop strategies for better selection and communication between sellers and consumers.

The ripening process of mango fruits is indeed influenced by temperature, which affects their physicochemical attributes over time. Temperature plays a crucial role in the ripening process of mango fruits. Lower temperatures, like 20°C, are better for maintaining fruit quality over an extended period, while higher temperatures, such as 25°C, might be suitable for quickly ripening mangoes with sweeter and more acidic characteristics. Still, they may not have the same shelf life as those matured at lower temperatures. Physiological loss in weight is a measure of moisture loss during ripening [5]. It is mentioned that at 20°C, mango fruits experience less physiological loss in weight compared to 25°C. This indicates that the fruit retains more moisture at the lower temperature. The information you provided summarizes the biochemical parameters of mango fruits, including their moisture content, carbohydrate content, total soluble solids (TSS), total sugar content, and the levels of vitamins A, B, C, and nicotinic acid [6]. It also mentions the change in sugar content as mangoes ripen and the similarity in moisture content between unripe and ripe mangoes. The author [7] shows in their research that a sugar component shows a symmetric increment at a mature state. Initially, the sugar value is less at the unripe stage, but the sugar component was found to be gained in maturity. The range of moisture in ripe mango is very similar to unripe mango, with a value of 78.9 % to 82.8 % per 100 g.

The information provided from the author's [8] discussion highlights the variation in bio-accessible β-carotene content in different mango varieties, emphasizing the importance of this antioxidant compound in mangoes. In addition to β-carotene content, the author also mentions various parameters that can affect the quality of mangoes during the ripening stage. These include temperature, controlled and modified atmosphere storage, ionizing radiation, and using chemicals for ripening or preservation. These factors play a significant role in determining the shelf life and overall quality of mangoes. Furthermore, the author suggests that internal parameters such as TAC (Total Antioxidant Capacity), SSC (Soluble Solids Content), and TA (Titratable Acidity) are crucial for grading mango quality. Monitoring these internal parameters is essential as relying solely on visual appearance may not be sufficient to detect internal defects or variations in quality. Early recognition of internal features is necessary, as the severity of defects can impact the financial value of mangoes. To address this, non-destructive methods are recommended to identify internal characteristics, reduce waste, and maintain the overall quality of mangoes throughout the supply chain. These internal quality parameters are often assessed visually, through taste tests, and by using various tools and instruments to measure specific attributes like sugar content and acidity. Accurate evaluation of these parameters is essential for ensuring that mangoes are harvested, stored, and distributed at the peak of their quality, which is crucial for domestic and international mango markets. Mangoes, like many fruits, are assessed for their internal quality based on various parameters that determine their taste, texture, ripeness, and overall desirability. Here are some of the critical internal quality parameters for mangoes:

Sugar Content (Brix): The sugar content, typically measured in degrees Brix, indicates the sweetness of the mango. Ripe mangoes have higher sugar content, making them sweeter.

Acidity (pH): The acidity level influences the mango's taste. The right balance of sweetness and acidity is important for a pleasant flavor. The pH value can also be an indicator of ripeness.

Aroma: The aroma or fragrance of a mango is a crucial quality parameter. A ripe mango should have a distinct, pleasant aroma that reflects its variety.

Firmness: The firmness or texture of the mango is assessed by touch. It should be neither too hard nor too soft. The texture changes as the mango ripens.

Flesh Colour: The colour of the mango flesh can vary by variety. It can be yellow, orange, or even red. The internal colour is an indicator of ripeness, with most mangoes turning from green to a more vibrant colour when ripe.

Fiber Content: Some mango varieties have fibrous flesh, while others are fibre-free. The presence and quantity of fibres can affect the eating experience.

Juiciness: Juiciness is an important quality parameter. Ripe mangoes should be juicy, but not excessively so.

Astringency: Some mango varieties may have astringent properties when unripe. As they ripen, this astringency decreases, which is desirable for consumption.

Taste and Flavour: The overall taste and flavour profile, including hints of tropical and citrus notes, contribute to the mango's desirability.

Defects: Any internal defects, such as bruising or rot, negatively impact the quality of the mango.

III. Physical Parameters for Ripped Mango

The width of most mango varieties is relatively consistent, with slight variation. 'Mallika' and 'Alphonso' varieties have the largest width. 'Samarbahist Chausa' has a narrower width of 57.0 mm compared to the other varieties. The dimensions of mangoes, such as length and width, are essential physical characteristics that can influence their appearance and, to some extent, their eating quality. These parameters help categorize and differentiate mango varieties based on their shape and size. Additionally, specific varieties, such as 'Totapuri,' stand out with distinctive characteristics, in this case, having the most extended length. The width of most mango varieties is relatively consistent, with slight variation. 'Mallika' and 'Alphonso' varieties have the largest width. 'Samarbahist Chausa has a narrower width of 57.0 mm compared to the other varieties [7].

The information provided highlights various physical parameters and characteristics of different mango varieties, including weight, volume, and specific gravity, as well as carotenoid content. Mallika mangoes have the highest width, measuring 382.23 g. They also have the highest importance, with a value of 373.33. Fazli and 'Langra' Varieties follow 'Mallika' regarding width and volume. ‘Samarbahist Causa’s mangoes are comparatively lighter, weighing 173.33 g. They also have a smaller volume, measuring 93.7 ml. Specific gravity is a measure of density, and it varies among different mango varieties, ranging from 1.095 to 1.022. This indicates differences in thickness and composition among the mango varieties.' Alphonso and 'Fazli varieties have the lowest carotenoid content, with values of 2.65 mg/100 and 1.82 mg/100, respectively. Carotenoids are pigments responsible for the color of many fruits and vegetables. These parameters, including weight, volume, specific gravity, and carotenoid content, provide valuable information for assessing and characterizing different mango varieties. The variations in these attributes can influence the fruit's appearance, taste, and nutritional value. Consumers and the industry must understand these differences to choose the mango variety that suits their preferences and needs.

The presence and levels of carotenoid content in mango varieties can vary, and these variations are often due to specific carotenoids, including β-carotene, lycopene, lutein, and zeaxanthin. Carotenoids are responsible for the coloration of many fruits and vegetables and are crucial for their nutritional value. Identifying fruit ripening often depends on measurable attributes such as titratable acidity [8]. Titratable acidity is a measure of the fruit's acidity, and it can change with the ripening process. Ripening is also influenced by prevailing environmental conditions, including temperature and humidity, as well as ecological factors. The variations in acidity levels among different mango varieties can be attributed to their inherent characteristics, which are influenced by environmental and ecological conditions. These variations are natural and can be considered a part of the mango's genetic diversity. The increase in ascorbic acid (vitamin C) content in mangoes during their growth and development may be due to the continuous synthesis of glucose 6-phosphate, a precursor for ascorbic acid. This increase may also result from the catalytic effect of growth-promoting substances on the biosynthesis of ascorbic acid from sugars [9]. In summary, the presence of carotenoids, the changes in titratable acidity, and the increase in ascorbic acid content in mangoes are complex processes influenced by genetic factors, environmental conditions, and biochemical pathways. These factors contribute to the unique qualities and nutritional profiles of different mango varieties.

The physical parameters of ripened mango cultivars grown in India can vary depending on the specific variety, growing conditions, and maturity stage. These physical parameters are essential for grading, quality assessment, and marketing mangoes in India. The particular values and characteristics of these parameters can differ from one mango cultivar to another, and the mango industry often relies on grading standards to ensure consistency and quality in the marketplace. However, here are some of the standard physical parameters used to assess ripened mangoes:

Size: The size of ripened mangoes can vary significantly depending on the cultivar. Common mango varieties in India include Alphonso, Kesar, Langra, and Dasheri, and each has its characteristic size and shape.

Weight: Mangoes can vary in weight based on their size and maturity. The weight is an essential parameter for grading and pricing.

Shape: Mangoes can be oval, round, or somewhat oblong, and their shape is a distinguishing feature of different varieties.

Colour: The external colour of ripened mangoes varies with the variety. For instance, Alphonso mangoes are known for their bright yellow or orange skin, while Langra mangoes often have a greenish-yellow skin when ripe.

Skin Texture: The texture of the mango skin can be smooth or slightly wrinkled, depending on the variety. It should be firm but yield to gentle pressure when ripe.

Flesh Texture: The flesh of ripe mangoes should be smooth and juicy. The texture can vary from buttery to fibrous, depending on the variety. Some mangoes are known for their fibre-free flesh.

Aroma: Ripe mangoes are known for their pleasant, fruity fragrance. The intensity and type of aroma can differ among mango cultivars.

Fruit Maturity Stage: It's essential to assess the mango's maturity stage. A ripened mango should be neither underripe nor overripe. The set of ripeness can affect the texture and taste.

Seed Size: The size and shape of the seed or stone inside the mango can vary among cultivars. Some varieties have smaller roots, which means more edible flesh.

Juiciness: Ripe mangoes should be juicy, and the juice content can vary among different mango cultivars.

Taste and Flavour: The taste and flavour of mangoes vary widely between cultivars. Some are exceptionally sweet and have unique flavour profiles.

IV. NON DESTRUCTIVE MEASUREMENT

A non-destructive estimation is the assessment of materials in terms of shape, biochemical, and qualities without crushing their usefulness, just as the framework highlights. The conventional approach to identifying the inner attributes of fruit needs a destructive technique using apparatus, strategies, and training professionally, which brings about high examination costs. All this author says that [10] new advancements to keep track of fruit quality changes during the post-harvest taking care of chain are quickly being presented, particularly those dependent on non-destructive evaluation strategies. Hence, non-destructive methods allow supplanting the standard reference strategy, including the traditional methodology. Right now, non-destructive methods are utilized in mechanical applications to guarantee the practicability of a given item or framework. Non-destructive methods are significant in deciding the dependability of different applications, remarkably in assessing the quality parameters of fruits. These efficient and non-ruinous strategies can benefit by furnishing definitive attributes to acquire better quality mango items and advancing utilization of mangoes with better well-being benefits.

A. Infrared based spectroscopy

The author [11] has used VIS-NIR spectroscopy with a robot gripper for mango quality grading. They have also presented the framework which describes the working model of spectroscopy in robot gripper. The author [12] has also utilized the near-infrared reflection spectroscopy to acquire the spectra. The range of NIR spectroscopy is between 400 to 700 nm. The passage describes a study using VIS-NIR spectroscopy with a

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robot gripper for mango quality grading. Here are the key points from the selection:

Use of VIS-NIR spectroscopy: The author used visible and near-infrared (VIS-NIR) spectroscopy to assess mango quality.

Framework for spectroscopy in robot gripper: The author presented a framework that outlines how spectroscopy can be integrated into a robot gripper for mango quality grading. This suggests an automated system for assessing mango quality.

Near-infrared reflection spectroscopy: Near-infrared (NIR) reflection spectroscopy was employed to capture the spectra of the mango samples. The NIR spectra were obtained in the range between 400 to 700 nm, with readings taken at 10 nm intervals.

Data collection: Mango data samples were collected for experimental purposes. These samples were kept at a specific temperature (24±10°C) before the measurement of the spectra. Temperature control is important to ensure consistent measurements.

Raw spectra and noise removal: The raw spectra collected had high dimensions. To prepare the data for analysis, a pre-processing step was conducted to remove noise from the raw spectra. This was achieved by applying weight regression coefficients.

Analysis of internal parameters: After pre-processing, internal parameters like Total Soluble Solids (TSS), Total Acidity (TA), and firmness were analysed using a Partial Least Squares (PLS) model. PLS is a technique used for diagnosing the relationship between predictor variables (spectra) and response variables (in this case, TSS, TA, and firmness) to make predictions or assessments.

The study appears to be focused on developing a system for automated mango quality grading using spectroscopic data, and the passage describes the data collection, pre-processing, and analysis steps involved in the research. The author presents a framework based on electrical impedance spectroscopy to identify maturity levels to assess mango quality [13]. In this, 'Tommy Atkins' variety of mango has been utilized in the experiment. The data sample was washed and kept at different degrees of temperature for 15 days before the experiment. The electro-mechanic universal machine with TESC software is utilized for mechanical tests. With this, the mango sample was connected by two electro nodes. Finally, the maturity of mango can be obtained by calculating fitting results divided by mango fruit diameter. The author [14] presents a NIR spectral framework with a combination of an NIR spectrometer and a tool for mango fruit positioned, in this, internal parameters such as Dry matter (DM), TA, SSC, and ripeness will be reviewed to grade the quality of mango fruit. At last, MLR and PLS regression model is used to analyse the data. The outcomes show that NIR is a promising strategy to explore the relationships of biochemical parameters of the same mango product at various formative stages. With this recently created technique, a pattern estimation of value changes during fruit product improvement dependent on inspecting different mango samples is never again required. Some author, for example, [15], have enclosed in their research the full range utilizing spectroscopy in mangoes, even though reviews using colour arranges are increasingly expected, for example, [16].

Over the past few years, X-ray has given a quality-based 3D image of objects with various materials, making a difference in separating low-and high-density materials. To fulfil this intention, the author [17] has studied the physical properties of cucumber fruit. The physical properties such as density, porosity, moisture content, and Firmness is estimated for seven continuous days at different temperature. Respectively, X-ray techniques are applied to the sample to collect the 3D –image. Further segmentation method was performed to obtain the average gray value of the pixel. Finally, by using regression techniques, the change in fruits is analysed. They have also expressed that in higher temperatures of 25 C, the average value grayscale decreases, whereas increment is observed in the internal porosity parameter. In their study, authors [18] evaluated the porosity in fruits and vegetables by applying X-ray CT. They also presented the framework where an X-ray machine scanned an image sample. This machine has ranged between 746 mm to 1085 mm with 120 KV. Further, two tissue sample with high and low resolution is analysed.

B. Machine vision

Machine vision is a part of an engineering expert skill in consolidation with optical and mechanical properties, electromagnetic, and image processing methods. Machine vision frameworks are progressively faster regarding sample image assessment when analyzing acoustic and vibration techniques. The improvement of the application has increased a lot of enthusiasm for the quality assessment of agricultural products. The volume estimation is essential for fruit to decide the size per specific grading evaluations [19]. At the present stage, the principle worries in this machine vision explore the capacity of machine vision to classify the agriculture product regarding quality parameters. Till now, research has dealt with the primary practice of quality assessment with methods for machine vision frameworks. But, just a couple of the present works discussed the physicochemical and biochemical presence in the image sample [20].

In a computer vision-based system, each image is represented in some particular color space. Many color spaces are available in image processing. Some common color space is RGB color space, HSI color space, L* a* b* color space, etc. [21]. For example, the RGB color space is frequently utilized in exacting R G B individually of mango fruits, which contains the three wavelengths with the composition of red, green, and Blue. As we know, RGB color space is hardware-based. Color changes have been done by the standard color value of the particular image that can be identical to a human person in HSI color space [22]. The machine vision framework plays a vital role in detecting color, texture, shape, and illumination. Identifying disease or external damage is ongoing with further, more challenging tasks. Particularly since the present measurement relies upon the high discrepancy of disease. For instance, the exactness of the machine vision framework to assess the external part of food products depends upon a few elements, including the cultivar, planting area, and postharvest treatment of fruits [23].

The author [24] has presented a computer vision approach to improve productivity. This system comprises a camera, frame grabber, and sample holder component. In this, image samples are kept on a sample holder. This image holder is connected to the camera, which captures the image and forwards it to the next stage, where the image is collected in frame format using the frame grabber component. The system is connected by wired with all members of the proposed framework. They have analyzed the review of various fruits and vegetables. Image processing techniques mostly do the quality analysis of fruits and vegetables. This technique consists mainly of four steps: the first step is to do pre-processing to remove unwanted noise, the second segmentation process to extract the background of the image sample, feature extraction to extract the parameter responsible for the quality, and finally, applying classifiers to detect the proposed system's performance.

The author [25] first prepared the image acquisition chambers to grade the mango quality. A design framework was presented by the author [26]. The layout of the system is helpful for fruit grading. This module combines components such as conveyor belts, fruit placers, image-capturing chambers, fruit sorting strips, and sorting bins. In this back propagation neural network (BPNN) is utilized at the classification stage to sort the fruit based on respective quality. 80.0 percent accuracy rate is achieved by the proposed system for grade II fruit, whereas 71 percent accuracy for grade I and 66 percent for grade III date fruit has been achieved. The author presents a computer vision framework for mango grading [27]. Author [28] also presents the Machine Vision system for the quality determination of mango. This framework consists of components such as Conveyed assembly, Electric power drive, Fruit samples, Illumination unit, Light sources, Camera, Control unit, Computer, Frame grabber software, and Variable-frequency control. For the experimental purpose, the author collected two different categories of mango, 'Nam Dokmai' and 'Maha Chanok'.

Further, all sample images of mangoes were segmented by the Gamma Curve Fitting method. All the backgrounds extracted from the mango image are processed in the next step, where the color of each mango sample is calculated by the first Quadrant method. They have utilized the L* a* b* color space. Finally, in the calibration model, both mango 'Nam Dokmai' and 'Maha Chanok' categories are classified by static methods such as Mean and standard derivation. The grading of mangoes is done based on three different types: ripe, unripe, and overripe. The author presents an artificial intelligence-based structure for sorting mangoes [29]. Their study briefly described the role of image processing and AI in sorting the mango. The present model helps capture the image of the mango. Next, the segmented process and all features are extracted to obtain a segmented image of the mango based on color, mass, and volume features. Finally, ANN-based regression method quality grading has been done. The proposed system has produced 80 percent accuracy rates for sorting mangoes. A hardware and software-based model system is explored to sort a mango by the author [30-32]. They have utilized a conveyor belt, AC motor controller, webcam, sensor, and serial combination board. In this model, mango samples are kept on conveyor belts that pass through a webcam device to capture the image. Then, the image is segmented by Threshold techniques. The dilatation and erosion method is applied to the respective segmented image to remove the unwanted noise or shadow. This dilatation and erosion operation plays a vital role in improving the performance of the proposed system. Further, the size of the mango sample is based on the caliber determination method. This method extracts the pixel value of images based on the weight of the respective image. The proposed system achieves a percentage of accuracy rate. The quality of mango fruit significantly relies on numerous parameters, such as ripe, unripe, overripe, texture, shape, color, and other factors at harvesting time.

Object recognition and classification is an essential application in computer vision systems. The framework presented by the author [33] consists of four parts. Firstly, the mango image is segmented Ostu Threshold- Techniques. Next, the feature is extracted by using Region and Boundary descriptors. Finally, a 90.01 percent accuracy rate is achieved by applying Bayes classifier. A similar type of framework is presented by the author [34]. They must grade the mango by regression model based on mass and volume features. The proposed system produces a 91.76 percent accuracy rate for grading mangoes.

V. ADVANTAGES OF NON-DESTRUCTIVE METHOD

Non-destructive methods offer several advantages in various fields, including agriculture, food processing, quality control, and scientific research. Overall, non-destructive methods are versatile and essential in many applications, offering a balance between thorough assessment and preservation of samples, efficiency, and cost-effectiveness. They play a crucial role in quality control, research, and safety across various industries.

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Here are some of the key advantages of non-destructive methods:

- **Preservation of the Sample:** Non-destructive methods allow for the evaluation and assessment of a sample without causing any damage or alteration. This is particularly valuable when dealing with limited or valuable specimens.
- **Reduced Waste:** Since non-destructive methods do not damage or consume the sample, there is minimal to no waste generated during the testing or analysis process.
- **Cost-Effective:** Non-destructive methods can be cost-effective in the long run. While the initial investment in equipment and technology may be significant, it often leads to savings by reducing the need for extensive sample preparation or disposal costs.
- **Efficiency:** Non-destructive methods are often faster and more efficient than destructive ones. They can provide immediate results and reduce the need for time-consuming sample preparation or retesting.
- **Safety:** Non-destructive methods are generally safer for operators since they do not involve the handling of hazardous or toxic materials or the risk of exposure to harmful conditions.
- **Non-Invasive:** Non-destructive methods are non-invasive, making them suitable for sensitive or fragile materials, living organisms, and cultural artifacts. They are commonly used in medical diagnostics, archaeological studies, and the assessment of historic objects.
- **Real-Time Monitoring:** Many non-destructive methods, such as real-time imaging and sensor technologies, provide continuous or frequent monitoring of processes, structures, or materials, which is essential for quality control and safety.
- **Multiple Parameters:** Non-destructive methods can simultaneously assess multiple parameters or properties of a sample, providing a comprehensive view of its characteristics. For example, near-infrared spectroscopy can assess various chemical properties of a food product in a single measurement.
- **Sustainability:** Non-destructive methods align with sustainability principles by reducing waste and resource consumption. They support environmentally friendly practices by minimizing the impact of testing processes.
- **Quality Control:** In industrial settings, non-destructive methods are crucial for quality control and ensuring that products meet the required specifications without compromising the integrity of the samples.
- **Non-Contamination:** Non-destructive methods eliminate the risk of contamination, ensuring that the sample remains in its original state and free from contamination that could occur during handling or analysis.

VI. DISDVANTAGES OF NON-DESTRUCTIVE METHOD

While non-destructive methods offer many advantages, they also have certain disadvantages and limitations. It's important to consider these drawbacks when choosing between non-destructive and destructive methods for specific applications. It's essential to carefully evaluate the specific requirements of an application and weigh these disadvantages against the benefits of non-destructive methods when choosing the appropriate testing or measurement approach. In some cases, a combination of non-destructive and destructive methods may provide the most comprehensive assessment. Here are some of the disadvantages of non-destructive methods:

- **Limited Sensitivity:** Non-destructive methods may have limitations in their ability to detect subtle changes or defects, especially in cases where the changes are below the method's detection threshold. This can lead to false negatives or missed issues.
- **Cost of Equipment:** The initial cost of acquiring and maintaining non-destructive testing or measurement equipment can be high, making it a barrier for smaller organizations or those with limited budgets.
- **Complexity:** Some non-destructive methods can be complex to implement and require skilled operators or technicians to obtain accurate results. This complexity can lead to higher operational costs and potential for human error.
- **Sampling Variability:** The accuracy of non-destructive methods can be affected by variability in sample properties, shape, and orientation. Variations in sample composition can also impact the results.
- **Calibration and Standardization:** Non-destructive methods often require calibration and standardization to provide reliable results. Failing to maintain the equipment and standards can lead to inaccuracies.
- **Time-Consuming:** Non-destructive testing can sometimes be time-consuming, particularly when it involves extensive setup, data collection, and analysis. This may not be practical in situations that require rapid results.

VII. MACHINE LEARNING IN FOOD INDUSTRIES

Machine learning is increasingly being applied in the food industry to enhance various aspects of food production, processing, quality control, and distribution. Here are some key areas where machine learning is making a significant impact in the food sector: The author [36-38] has introduced a framework by NIR spectroscopy. In their study, non-infrared spectroscopy is utilized to assess the internal features of mangoes. Machine learning in the food industry relies on a wealth of data sources, including sensor data, image data, chemical analyses, and consumer preferences. By leveraging this data, machine learning models can improve the efficiency and quality of food production and distribution while addressing critical issues like food safety and waste reduction.

Quality Control and Inspection:

- Machine learning algorithms can be used to automate the inspection of food products for defects, contamination, and quality issues. Computer vision systems can identify visual anomalies and sort out subpar products.

Food Safety and Traceability:

- Machine learning can help in food safety by predicting and identifying potential contaminants, pathogens, and allergens. It can also be used for early warning systems to detect outbreaks.
- Machine learning are employed to track and trace food products throughout the supply chain, ensuring transparency and authenticity.

Quality Prediction and Shelf-Life Estimation:

- Machine learning models can predict the quality and shelf life of food products based on various factors, including storage conditions, packaging, and initial quality.
- These predictions are valuable for inventory management and reducing food waste.

Supply Chain Management:

- Machine learning is used for demand forecasting, inventory optimization, and logistics planning. It helps in reducing food spoilage and optimizing distribution.
- Predictive analytics can also mitigate the impact of supply chain disruptions or unexpected events.

Food Authentication and Fraud Detection:

- Machine learning can be employed to detect food fraud and adulteration by analyzing various data sources, such as chemical compositions and spectral data.
- It can authenticate the origin and quality of products, including verifying the authenticity of premium labels like organic or certified products.

Nutritional Analysis:

- Machine learning models can estimate the nutritional content of food products based on their ingredients and composition.
- Apps and platforms use machine learning to provide nutritional recommendations and personalized dietary advice to consumers.

Flavor Profiling and Development:

- Machine learning can help food companies create new flavor profiles by analyzing ingredient combinations, aroma compounds, and sensory data.
- It can assist in developing unique and appealing food products.

Precision Agriculture:

- In the context of agriculture, machine learning is used for crop management, irrigation control, and disease detection, which indirectly impacts the quality and availability of food products.

Waste Reduction:

- Machine learning systems can help reduce food waste by optimizing production, distribution, and inventory management.
- Apps and platforms can provide consumers with information on minimizing food waste through recipes and meal planning.

VIII. PROBLEM IDENTIFICATION

Grading the quality of mango fruit is a crucial process in the fruit industry to ensure that only mangoes of desired quality reach the market or processing facilities. However, this task can be challenging due to the variability in mango quality and the subjectivity involved in human grading. Using automated systems and technology, such as machine learning and computer vision, can help address these issues. Grading the quality of mango fruit is currently a manual and subjective process, which can lead to inconsistencies and inefficiencies in the fruit supply chain. There is a need for an automated, objective, and accurate grading system that can assess various quality parameters, including color, size, ripeness, and external defects, to ensure uniform, high-quality mangoes are delivered to consumers, processors, and export markets. This system should also accommodate different mango varieties, as their quality parameters may vary.

IX. PROPOSED ARCHITECTURE

While non-destructive techniques offer several advantages, it's important to acknowledge their limitations, including the initial cost of technology acquisition, the need for calibration and standardization, and potential challenges related to environmental conditions and sample variability. The development and adoption of non-destructive grading methods in the mango industry hold great promise for enhancing the efficiency and reliability of mango quality assessment, ensuring consumers receive high-quality, consistent, and safe fruit while also benefiting the industry by reducing operational costs and minimizing waste. Further research and collaboration between technology providers, mango producers, and regulatory bodies will be crucial in the successful implementation and standardization of non-destructive grading systems for mango fruit. Creating an architecture to grade the quality of mango fruit involves integrating various technologies and components to automate the grading process efficiently and accurately. This architecture provides a high-level overview of the features and stages of a non-destructive mango grading system. The successful implementation of such a system requires a collaborative effort between technology providers, mango producers, and regulatory bodies to establish industry standards and ensure the quality and consistency of mango grading processes. Below is a high-level architecture that outlines the key components and stages of a non-destructive grading system for mangoes:

1. **Data Acquisition:** Utilize a combination of sensors, cameras, and imaging systems, including hyperspectral cameras, near-infrared (NIR) spectroscopy, and colour cameras, to capture data from mangoes.
2. **Data Preprocessing:** Data Cleaning and Enhancement: Apply preprocessing techniques to clean and enhance the raw data, including noise reduction, outlier removal, and calibration.
3. **Feature Extraction:**
Extract relevant features from the data, such as colour, size, spectral signatures, and texture, for the grading process.
4. **Real-Time Grading:**

- **Integration with Conveyor Systems:** Implement the grading system in conveyor lines to allow mangoes to pass through the inspection area.
- **Computer Vision Cameras:** Use high-resolution cameras and sensors to capture images and data from mangoes in real time.
- **Quality Prediction:** Apply the machine learning models to predict the quality of each mango as it passes through the inspection area.

5. **Grading and Sorting:**

- **Quality Grading:** Based on the predictions, assign a quality grade to each mango, such as "premium," "standard," or "reject."
- **Sorting Mechanisms:** Implement sorting mechanisms, such as robotic arms or air jets, to divert mangoes into appropriate bins or conveyor lanes based on their quality grade.

6. Data Storage and Analytics:

- **Data Logging:** Store all grading data, including quality assessments and environmental conditions, for traceability and analysis.
- **Data Analytics:** Analyse historical data to identify trends, improve quality, and optimize the grading process.

7. Reporting and User Interface:

- **User Interface:** Develop a user-friendly interface for operators and quality control personnel to monitor the grading process, adjust settings, and view quality reports.
- **Quality Reports:** Generate detailed quality reports for each batch of mangoes, including statistics on the distribution of quality grades.

8. Integration with Supply Chain: Connect the grading system with the broader supply chain, allowing for seamless tracking and traceability of mangoes from the point of grading to the consumer.

9. Maintenance and Calibration:

- **Regular Maintenance:** Establish a maintenance schedule to ensure the continued accuracy and reliability of sensors and equipment.
- **Calibration:** Regularly calibrate the system to account for changes in environmental conditions and ensure the quality assessments remain accurate.

XI . CONCLUSION

In conclusion, non-destructive techniques for grading the quality of mango fruit offer a promising approach to enhance the efficiency and accuracy of mango quality assessment. This review highlights the key points and advantages of using non-destructive methods for mango grading. In this paper, we surveyed fruit's internal and external parameters to grade the quality based on their properties. We additionally analyze the non-destructive measurement to evaluate the internal parameter; further, various method of pre-processing spectra is discussed. Finally, the role of machine learning techniques in the food industry is briefly examined. Literature review and analytical comparison have been made among recent state-of-the-art internal and external features applying destructive and destructive, based on which the five most challenging research gaps are identified that need to be addressed.

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