**IMAGE PROCESSING TECHNIQUES FOR QUALITY EVALUATION OF FOOD**

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**Abstract:** The modern food industry places a premium on quality because it is the foundation for success in the current market's fierce competition. It is vital to enhance quality control procedures in order to meet consumers' rising awareness, sophistication, and expectations. When used in conjunction with effective image processing techniques, machine vision effective tool which can give helpful data for the quality of goods and the impact of the processing regime.

***Keywords:*** *Image processing, X-ray, hyperspectral imaging, food quality, thermal imaging*

1. **Introduction**

Food quality is defined as degree of excellence of food includes factors such as taste, appearance, and nutritional quality. Sensory and objective evaluationmethods are used in food industry in order to routinely monitor food quality and to ensure that the foods being produced are acceptable to the consumer. Researchers have recently created different non-contact methods for evaluating food and beverage goods, which overcome the majority of the shortcomings of conventional approaches like human inspection. These techniques work by automatically identifying different visual aspects that may connect with qualities relating to sensory, chemical, and physical properties. Processing digital photos using a digital computer is referred to as a form of digital image processing. The food industry ranks among the top ten industries using image processing techniques, which have been proven successful for the objective and non-destructive evaluation of several products (Valous and Sun, 2012).

Image processing can be used as th method for enhancing the raw images that sensors and cameras capture. Compared to destructive approaches, it is a non-destructive process that is also relatively quick and affordable (Aulakh and Banga, 2012). For image processing of any image we have to collect the images by using image acquisition. Image acquisition contains light source, sensor or camera, black background for absorption of lights and computer system.

1. **STEPS IN IMAGE PROCESSING**
2. **Image Acquisition**

 Image acquisition is the action of retrieving an image from some source. Image acquisition is crucial to image processing because if the images are not captured correctly, even with various enhancement techniques present, the various image processing algorithms may not be very effective (Joseph, 2018).

1. **Image Enhancement**

 The process of improving digital images makes them more suited for display or additional picture analysis. The primary goal of the image enhancement system is to create techniques that are quick, effectively handling noise, and perform precise segmentation.

1. **Image Restoration**

 Restoring or recovering a picture which has been destroyed by degradation processes is attempted. Image restoration is the process of restoring a corrupted or deteriorated image by reducing noise or blur to enhance the image's appearance. The original image, the deteriorated function, and the additive noise are convolutional to create the degraded image. With the use of previous understanding of the noise or disturbance which leads to the image degradation, the image might be restored.

1. **Wavelets and Compression**

The basis for describing images at different resolution levels is wavelets. Wavelet offers tools for decoding and creating signals and visual data. to denoise and compress data, and to recognize events like anomalies, switch points, and transients. To disassemble signals and images into their component elements and examine data at various time and frequency resolutions, and multiscale techniques such as wavelet analysis can be utilized. To train machine and deep learning models, wavelet technique is used to reduce dimensionality and extract distinguishing characteristics from sign**a**ls and images (Sonka *et al*., 2008).

1. **Image Segmentation**

 Image segmentation is the division of input picture into sections which are homogenous with regard to a certain image quality, such as intensity, colour, or texture. It may employ thresholding, edge detection, area identification, statistical classification, or a combination of these methods. Typically, the segmentation process results in a set of categorized elements (Valous and Sun, 2012).

1. **Representation and Description**

 The output of a segmentation phase follows by representation and description. This output is frequently raw pixel data and depicts the area's boundaries or all of its points.

1. **Recognition**

The act of giving a label to an item depending on its descriptors is known as recognition. The goal of object identification is to teach a computer to recognize a certain object under a variety of lighting, background, and perspective conditions.

1. **Imaging Techniques**

Different imaging techniques which are non-destructive can be used for determination of quality and defect detection in food produce and products such as X-Ray, computed tomography, hyperspectral, fluorescence, magnetic resonance, structured illumination reflectance, thermal imaging and machine vision (Rajarathnam and Ramteke, 2011).

1. **X-Ray Imaging**

Wilhelm Conrad Rontgen, a German physicist, made the discovery of X-rays in 1895. He received the first physics Nobel Prize for discovering X-Rays, often known as Rontgen rays. However, X-rays were first used to inspect food and agricultural products in the 1920s. As an electromagnetic radiation, X-rays have shorter wavelengths and more penetrating strength than visible light. It has a wavelength between 0.01 and 10 nm and energies between 100 eV and 100 KeV. Fast travelling electrons from a hot cathode collide with a heavy metal target to produce X-rays. An evacuated tube with a filament-like cathode and a metal target known as an anode make up a standard X-ray tube. The usage of gas-type X-ray sources with both positive and negative charge electrodes has been replaced by the use of filament-type cathodes that are commonly made of tungsten. The tungsten filament must be heated to a minimum of 2,200°C in order to emit electrons. The cathode, which is kept at a strong negative potential, emits electrons that are drawn to the anode, which is kept at ground potential in a vacuum. Through a significant voltage, the accelerated electrons strike the target and emit X-rays (Karunakaran and Jayas, 2014).

The choice of the suitable tube voltage and current has a significant impact on the quality of the X-ray picture for each type of fruit since the thickness, density, and X-ray absorption qualities of different fruits vary (Jiang *et al*. 2008).

The potential of X-ray technology in the food business to identify internal flaws and contamination of the products has been determined by many researchers. One benefit of the technique is its ability to detect metallic and nonmetallic impurities in food products, including metals, bone, glass, stone, plastics, and rubber (Schatzki *et al*. 1996). Because processed meals have more or less consistent thickness and metallic and nonmetallic impurities have different densities from food ingredients, X-ray inspection systems are particularly appealing to the food industry. Fruit, vegetable, nut, and grain infestations are complicated since they may not be externally obvious and are difficult to physically detect. Insect eggs start to form during the flowering stage and do most of their growing inside the fruit's seed. The fruits could eventually suffer increasing harm as a result of the infestation.

**Table 1: Applications of X-Ray Imaging**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Application**  | **Voltage (kV)**  | **Current****(μA)**  | **Accuracy****(%)**  | **References**  |
| Wheat | Detection of sprouted wheat kerneFungal infection detection (*Aspergillus niger, A. glaucus* group, and *Penicillium spp*.) | 13.513.6 | 185184 | 8782 | Neethirajan *et al.,* 2007Narvankar *et al.,* 2009 |
| Banana  | Microstructure of banana slices  | 60  | 167  |  | Leonard *et al.,* 2008  |
| ApplePeach TomatoGuava  | Automatic defect detection system  | 65-75 | 125  | 10010093.9100  | Chuang *et al.,* 2011  |
| Salmon fish  | Bone detection  | 40  | 21 mA  | 99  | Mery *et al.,* 2011  |

1. **Computed Tomography Imaging Technique**

 Computed Tomography technique introduced in 1970 by Godfrey Hounsfield and Allan Cornack. They got Noble prize for discovery of CT scan technique. After commencing the CT scan in the control room and through the X-ray tube, samples are introduced into the CT scan crate to perform the imaging. On the sample, X-rays were made. The light colours of the pears were absorbed by the crystals in the CT scan, and some of the energy was taken up by the sample while the remaining rays were rejected. They were then transformed into image codes using a light converter and sent to a room with computers to recreate images. According to Lim and Barigou (2004), it took roughly 30-45 min to scan a 10 mm cube of cellular food products over 180° in 200 distinct steps of 0.9°. It has been discovered that employing X-ray beam projection, computed tomography may deliver comprehensive 3-dimensional information. It has been discovered that the 2-dimensional slices obtained from CT imaging exhibit higher contrast between the components of the corresponding slice. In contrast to transmission radiography, the generation of 2-D and 3-D slices takes longer.

 **Table 2: Applications of Computed Tomography Imaging**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Products**  | **Objective of Study**  | **Current** **(mA)**  | **Voltage****(kV)**  | **References**  |
| Sweet Potato  | Development of Weevil larvae and subsequent damage in infested roots  | 230  | 120  | Thai et al., 1997  |
| Apple  | Pore space quantification of apple tissue  | 156 (μA)  | 63  | Mendoza et al., 2007  |
| Wheat  |  Investigation of internal and structural features defects of wheat  | 96 (μA)  | 100  | Dogan, 2007  |
| Pear  | Pear bruise level determination due to external load  | 120  | 80  | Azadbakht *et al*.,2018 |
| Apple  | Water disorder  | 100  | 80  | Herremans *et al*., 2013  |

1. **Hyperspectral Imaging**

Hyperspectral Imaging is based on spectroscopy and conventional imaging. It provides both spectral and spatial information of the sample. It consisted of Light source (illumination), wavelength dispersion device (spectrograph), and detector (camera), computer with corresponding software.

The surface of the object absorbs the light from the source and then reflects it. Light of different wavelengths will have different levels of bend-divergence propagation after passing through the front lens and entrance slit. When it finally converges at the collimation lens, light of various wavelengths splits into distinct bands. Finally, the imaging lens will present the spectrum signal to the detector. By using machine sweeping, a three-dimensional data cube rich in spectral and picture data is produced. Additionally, it's important to focus on highlighting the object and minimizing the background when selecting the light source. Meanwhile, the signals to noise ratio of the image must be increased to provide meaningful signal as much as possible while reducing noise interference. One of the most essential parts of the hyperspectral system is the imaging spectrometer, also called as a hyperspectral camera, which absorbs, processes, and transmits the target's reflection spectrum. The electronic control platform's primary job is to regulate the object's movement and keep it in line with the camera's sampling rate and time of exposure in order to avoid the problem of missed or repeated acquisition. By primarily controlling the functioning of pertinent equipment through parameters setting, data acquisition software effectively completes the data gathering task (Zhu *et al*., 2020).

**Table 3: Applications of Hyperspectral Imaging**

|  |  |  |  |
| --- | --- | --- | --- |
| **Product** | **Application** | **Wavelength (nm)** | **References** |
| MangoesSoybeanPickling cucumbers  | Insect Infestation  | 400 – 1000400 – 1000450 –740740 –1000 | Saranwong *et al*., 2011 Huang *et al.,* 2013 Lu and Ariana 2013 |
| Maize Kernel  | Fungal Development  | 1900 and 2136  | Williams *et al.,* 2012  |
| Milk Powder  | Detection of melamine in milk powders  | 990-1700  | Lim *et al*., 2016  |
| Blueberry  | Internal browning  | 950-1650  | Fan *et al.,* 2017  |
| Cocoa Beans  | Prediction of fermentation index, polyphenol content and antioxidant activity  | 1000-2495  | Caporaso *et al*., 2018  |

1. **Fluorescence Imaging**

The foundation of fluorescence imaging is the idea that when specific electromagnetic radiation or visible light excite organic molecules, they produce distinctive fluorescence. Many fruit tissues are rich in chlorophyll, which can emit fluorescence near the maxima of 685 nm and 730 nm. Chlorophyll is lost when a fruit is crushed, which reduces the fluorescence excitation of the injured tissues relative to healthy tissues. The brightness of the images captured via fluorescence imaging are vary due to the diverse contents and are utilised to separate the injured tissues using some image processing techniques, such as threshold segment. Because it can only use chlorophyll as an index to reflect the wounded tissues, fluorescence is only used to detect tissues that are rich in chlorophyll (Du et al*.,* 2020).

**Table 4: Applications of Fluorescence Imaging**

|  |  |  |  |
| --- | --- | --- | --- |
| **Product** | **Application** | **Wavelength (nm)** | **References** |
| Grapes  | Assessment of anthocyanins in whole Grape (*Vitis vinifera L.)* Bunches  | 550 and 650  | Agati et al*.,* 2008  |
| Mandarin Orange  | Detection of rotten mandarin orange, the extraction and identification of fluorescent substances contained in rotten parts of mandarin orange  | 360-375 and 530 - 550  | Kondo et al*.,* 2009  |
| Tomato |  Discrimination of mature and immature green tomatoes (*Solanum lycopersicum L.*) | 365  | Fatchurrahman et al*.,* 2020 |
| Pickling Cucumbers | Detection of chilling injury | 675 and 750  | Lu and Lu, 2021  |

1. **Magnetic Resonance Imaging**

 By applying a powerful and consistent magnetic field to the hydrogen nuclei, which are mostly found in water, a high-resolution image can be generated. As a result of the object tissues' varying levels of contrast in reaction to both a magnetic field and radio frequency signals, the image is created. Magnetic resonance imaging, which is based on the idea of nuclear magnetism, uses radio frequencies and applied magnetic fields to interact with the magnetic properties of nuclei to produce images. MRI can analyse molecular dynamics in tissues using a variety of contrast mechanisms by detecting different types of object properties according to magnetic properties, such as proton density, chemical shifts, relaxation duration, heteronuclei, and diffusion constants. In order to create two-dimensional and three-dimensional images of the object that show tissues with varied contrasts depending on the different physicochemical properties for bruise diagnosis and grading, MRI is outfitted with magnetic gradient coils that can collect spatial data (Srivastava *et al.,* 2018)

**Table 5: applications of MRI**

|  |  |  |
| --- | --- | --- |
| **Product** | **Application** | **References** |
| Mango  | Internal quality assessment and monitoring of ripening | Joyce et al*.,* 2002 |
| Pears  | Core breakdown  | Lammertyn et al*.,* 2003  |
| Citrus | Internal quality assessment and monitoring of ripening | Galed et al*.,* 2004 |
| Pasta and Noodles  | Evaluation of texture and structure during and after cooking  | Lai and Hwang, 2004  |
| Meat  | Salt diffusion and water mobility in meat during brine curing  | Hansen et al*.,*2008  |
| Tomato and Pomegranate  | Internal quality assessment and monitoring of ripening  | Musse et al*.,* 2009Khoshroo *et al.,* 2011  |

1. **Structured-Illumination Reflectance Imaging**

 A computer-controlled digital light projector is utilized in a Structure-illumination Reflectance Imaging (SIRI) system to project shifted in phase sinusoidal patterns onto a sample, and a camera is used to record the reflectance image from the sample. A computer, a digital light projector with a radiometric power supply controller, and a back-illuminated electron-multiplying charge-coupled device camera with a fixed C-mount focal length lens make up the bulk of the system. For multispectral imaging, a liquid crystal tuneable filter (LCTF) is positioned in front of the lens, allowing any wavelength that falls in the spectral range of 650 to 1000 nm to be chosen. A linear polarizer is positioned in front the projector, which works with a liquid crystal adjustable filters to reduce specular reflectance. A fibre optic cable is utilized to route the lamp's output into the projector. It is run inside a small, dark room (Lu and Lu, 2019).

**Table 6. Applications of Structural Illumination Reflectance Imaging System**

|  |  |  |  |
| --- | --- | --- | --- |
| **Products** | **Applications** | **Wavelength (nm)** | **References** |
| Apple  | Subsurface Tissue Bruising  | 800-1000  | Li et al., 2016  |
| Apple  | Detection of fresh bruises  | 600-1000  | Lu et al*.,* 2016  |
| Peach  | Detection of early decay  | 690-810  | Sun et al*.,* 2019  |

1. **Thermal Imaging**

 Thermal Imaging is based on fact that all materials emit infrared radiation and measures the infrared radiation emitted from the object rather than reflected infrared light. Different materials have different physicochemical properties and have different thermal diffusivity differences. The basic fundamental of thermal imaging has relied on the object that releases infrared radiation in the infrared wavelength region of 0.75 until 100 μm.

 Thermal imaging devices operate in the short-wave to long-wave regions of the infrared spectrum. The vast majority of food business applications require the high sensitivity that the mid-wave infrared wavelength areas typically offer. The key variables that were impacted by the radiation's intensity were temperature and emissivity. It primarily consists of a computer, signal processor, and thermal camera with infrared sensors. The sample's infrared radiation was picked up by the infrared sensor, which transformed it into an electrical reaction before turning it into an image. The can be captured in a form a matrix of numerous colour levels that define a specific temperature, showing the temperature pattern of the sample. The infrared sensor works in such a way that the temperature rises when heated by the infrared radiation passing through the thermal imaging device. Apart from that, it does not need an illumination unit compared to the hyperspectral and multispectral imaging systems since it integrates a heating/cooling source in order to provide a thermal distribution. The selection of wavelength bands can be determined according to various aspects whereas the criteria of image processing analysis rely on the proposed application of the system. The types of the camera mostly differ on its spectral wavelengths, temperature range and image size (Du *et al.,* 2020).

**Table 7: Applications of Thermal Imaging**

|  |  |  |  |
| --- | --- | --- | --- |
| **Products** | **Applications** | **Wavelength (nm)** | **References** |
| Apple  | Watercore detection  | 8000–13,000  | Baranowski et al*.,* 2008  |
| Detection of early apple bruises  | 8000-14000  | Baranowski et al*.,* 2009  |
| Guava  | Chilling injury  | 700–1000  | Goncalves et al*.,* 2015  |
| Grapes  | Detection of volatile compounds released from decayed grapes  | 10,000- 11,000  | Ding et al*.,* 2017  |
| Mango  | Maturity Grading  | 700-1000  | Naik and Patel, 2017  |
| Blueberry  | Bruise detection  | 700-1000  | Kuzy et al*.,* 2018  |
| Tomato | Disease detection  | 700-1000  | Zhu et al*.,* 2018  |

1. **Machine Vision**

Machine vision is an engineering technology that combines mechanics, optical instrumentation, electromagnetic sensing, and digital image processing technology. Machine vision system development is frequently utilised as a nondestructive method that uses image analysis in its functioning. At present, machine vision is frequently used to identify surface insect damage in agricultural products, but identifying interior flaws is more difficult.

**Table: Applications of Machine Vision**

|  |  |  |  |
| --- | --- | --- | --- |
| **Products**  | **Applications**  | **Accuracy (%)**  | **References**  |
| Wheat | ClassificationDisease infection | 94 | Zayas *et al.,* 1996Ruan *et al.,* 1997 |
| Wheat, Barley, Oats, Rye | Classification of cereal grains | 98, 97, 100 and 91, respectively | Majumdar *et al.,* 1997 |
| Rice | Grading | 91 | Wan *et al.,* 2000 |
| Strawberries | Sorting | 98-100 | Bato *et al.,* 2000 |
| Sweet potato | Grading | 84 | Wooten *et al.,* 2000 |
| Papaya | Shape characteristics analysis for papaya size classification | 94 | Riyadi *et al.,* 2007 |

1. **Merits and Demerits of Imaging Techniques**

 Imaging techniques have been significantly reintroduced in recent years by a number of researchers in a number of applications or real-world applications in the food sector. The timeliness and ease of usage in normal operations are the key advantages that these approaches have over the conventional chemical and chromatographic methods. The usage of these technologies is nevertheless subject to a number of restrictions. The use of this technology in the food industry is still limited by problems relating to the availability of commercially viable and reliable instrumentation, the large amount of data generated during the analysis, the requirement for complex data analysis and algorithms, and the small number of samples in the majority of applications reported in the literature.

**Table 9: Advantages and limitations of Imaging Techniques**

|  |  |  |
| --- | --- | --- |
| **Methods**  | **Advantages** | **Limitations** |
| X –Ray Imaging  | It can detect internal defects based on density difference and thickness of the sample  | High costPoor penetration in a product with high water contentDifficult to differentiate normal and infested tissues with similar densities  |
| Hyperspectral Imaging  | Provides both spatial and spectral features for accurate segmentation  | High cost |
| Magnetic Resonance Imaging  | No harmful ionizing radiationHigh – resolution visual information of internal structure  | High cost  |
| Structured-illumination Reflectance Imaging  | Enhance the detection resolutionDepth-resolved detection by controlling spatial frequency  | Less speed  |
| Thermal Imaging  | Easy Handling and Portability | Sensitive to environmental conditionRelatively high costs to obtain high resolution images  |
| Machine Vision | Easy and Fast Consistent and cost effective Automated inspection of produce | Object identification being considerably more difficult in unstructured scenesArtificial lighting needed for dim or dark conditions  |

**CONCLUSION**

 The chapter's summary of new imaging methods for the food industry's concerns about food quality and safety. The development of inexpensive image processing systems is particularly crucial for the assessment of food quality in order to meet the demand for cost-effective solutions. Heavy-duty real-time applications still struggle to handle the massive data streams due to processing speed. On the one hand, creating sufficiently precise and efficient image processing algorithms can speed up the processing rate to match the demands of contemporary production. On the other hand, adding image processing algorithms to specialized technology can cut down on the amount of time spent processing images. Image processing techniques will become more and more crucial in determining the quality of food as a result of quick and inexpensive software and hardware solutions.

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