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Role of Hyperspectral Imaging in Post Harvest Technology of Fruits and Vegetables

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Hyperspectral imaging, known also as chemical or spectroscopic imaging, is an emerging technique that integrates conventional imaging and spectroscopy to attain both spatial and spectral information from an object. Spatial information refers to the organization and spreads of a substance in relation to a specific reference point, such as the arrangement of objects in a room or the distribution of resources in a geographic area. Spectral information involves data collected from various wavelengths or spectral bands within the electromagnetic spectrum, providing insights into the unique characteristics or properties of the material being analyzed, such as the composition of gases in the atmosphere or the composition of minerals in geological formations.

Light is a nonmaterial wave composed of oscillating electric and magnetic fields and, being nonmaterial, the wave can travel through a vacuum without the aid of a material substance (medium). Through the development of quantum theory during the twentieth century, it has been proved by several investigations that under certain circumstances light behaves as a wave, while under different circumstances it behaves as a stream of massless particles. A hyperspectral imaging system can capture light from frequencies beyond the visible light range. This can allow extraction of additional information that the human eye fails to capture. Thanks to the interaction of light with pigments and microstructure present in the horticultural produce led to the development of these types of technologies (Wu and Sun, 2013).

Components of a hyperspectral imaging system

Hyperspectral imaging system consists of five main components: camera containing a cooled two-dimensional (2D) light detector, spectrograph, translation stage, illumination units, and a computer. Each of these components has its own characteristics that influence the total accuracy of the system. To characterize the performance of the whole system, it is important to measure and optimize all parameters that influence the quality of the obtained spectral image. The sample/target is usually diffusely illuminated by a tungsten-halogen or LED source.

A line of light reflected from the sample enters the objective lens and is separated into its component wavelengths by diffraction optics contained in the spectrograph; a two-dimensional image (spatial dimension, wavelength dimension) is then formed on the camera and saved on the computer. The sample is moved past the objective lens on a motorized stage and the process repeated; two-dimensional line images acquired at adjacent points on the object are stacked to form a three-dimensional hypercube which may be stored on a PC for further analysis (ElMasry and Sun, 2010)

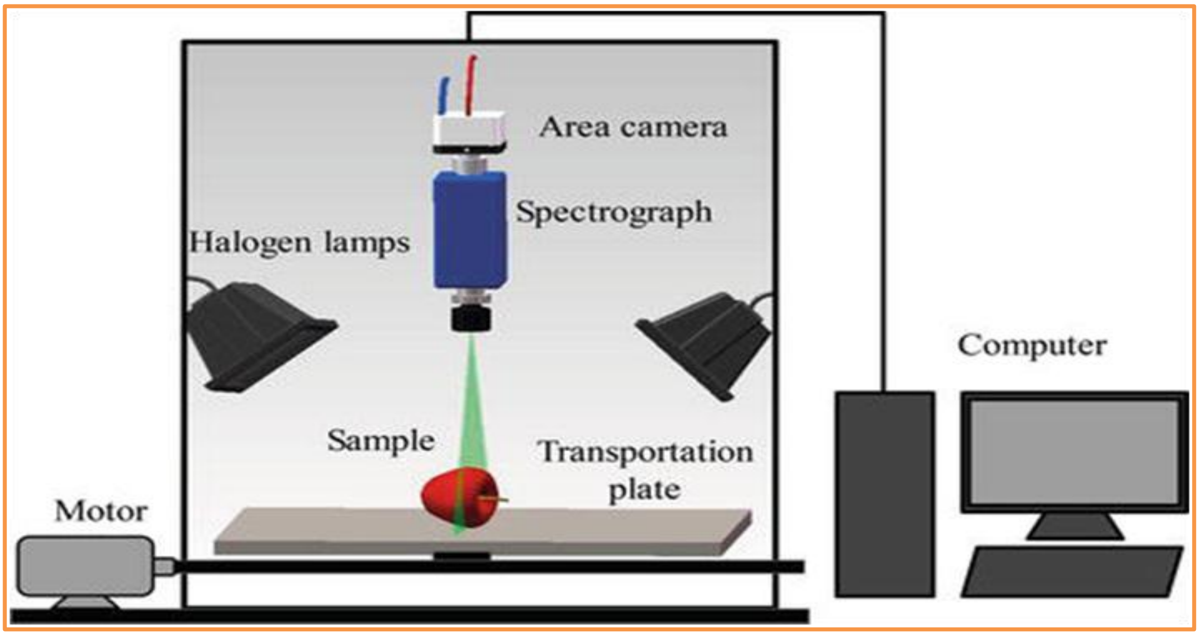

Fig. 1: Components of a hyperspectral imaging system

Imaging modes for generating hyperspectral images

(a) The reflectance mode: In this mode, the hyperspectral imaging system captures the reflection of light from the surface of the object or scene being studied. It measures the intensity of light reflected at various wavelengths, providing information about the surface properties and composition of the material.

(b) The transmittance mode: This mode involves measuring the light that passes through the object or sample being studied. It captures the transmission of light through the material across different wavelengths, which can provide insights into its internal structure, composition, or optical properties.

(c) The interactance mode: In this mode, the hyperspectral imaging system measures both the reflected and transmitted light from the object or sample. It combines information from both reflection and transmission, allowing for a comprehensive analysis of surface and subsurface properties, such as thickness, composition, and structural characteristics (Gowen et al., 2007).

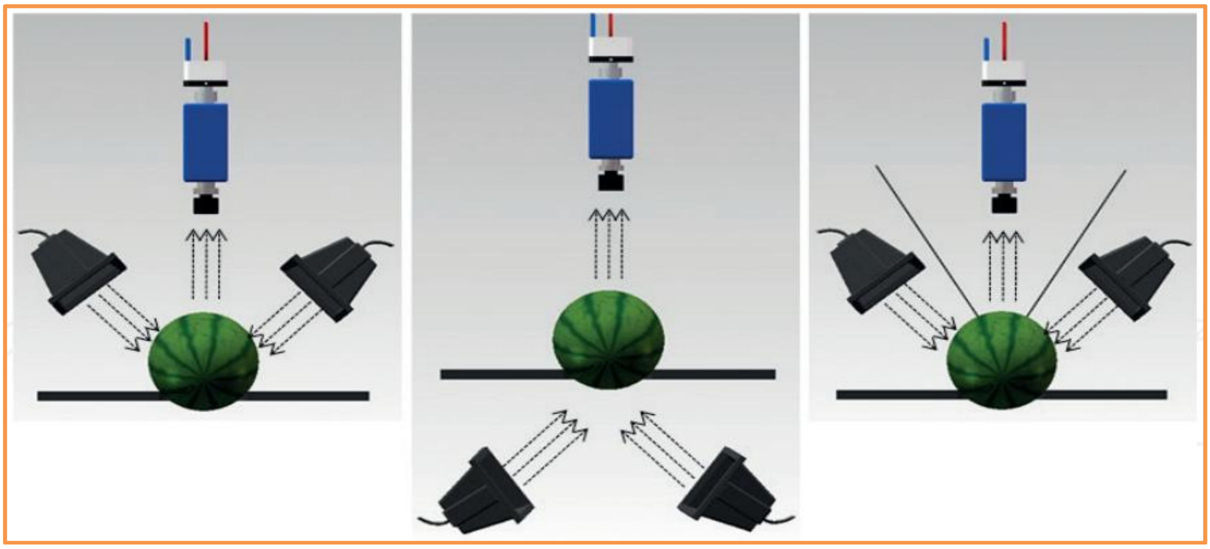

Fig. 2 Different modes for generating hyperspectral images

Applications of HIS in Post-Harvest Technology

Hyperspectral Imaging Systems find numerous applications in post-harvest technology, particularly in areas such as external quality and defect detection, internal quality and maturity evaluation, and food safety detection:

1. External Quality and Defect Detection: HIS can be employed to detect external defects in fruits, vegetables, and other agricultural products. By analyzing the spectral signatures of the surface, hyperspectral imaging can identify blemishes, bruises, mold, and other imperfections that may affect the quality or marketability of the produce. This application is crucial for sorting and grading operations in the post-harvest handling process, allowing for the automatic removal or segregation of defective or substandard items.
2. Internal Quality and Maturity Evaluation: Hyperspectral imaging can assess the internal quality and maturity of agricultural products without the need for destructive testing. By analyzing the spectral signatures of the internal tissues, HIS can determine parameters such as sugar content, ripeness, and physiological disorders. This information is valuable for optimizing harvesting schedules, predicting shelf life, and ensuring product consistency and quality.
3. Food Safety Detection: HIS can be utilized for the rapid and non-destructive detection of contaminants, pathogens, and other food safety hazards in agricultural products. By analyzing the spectral signatures associated with specific contaminants or microbial growth, hyperspectral imaging can identify potential risks such as pesticide residues, foreign objects, and microbial contamination. This application enhances food safety protocols by enabling early detection and intervention, reducing the risk of foodborne illnesses and ensuring compliance with regulatory standards (Lu et al., 2020).

Hyperspectral imaging systems offer several advantages, including minimal sample preparation and a non-destructive approach, making them suitable for rapid and repeated analyses. They enable fast acquisition times and provide a chemical-free assessment method, which enhances safety and environmental sustainability. Over time, they prove to be more economical compared to traditional analytical methods. Additionally, hyperspectral imaging allows for the simultaneous visualization of the spatial distribution of numerous chemical compositions, offering comprehensive insight into the sample's properties (Rady et al., 2017). Despite its advantages, hyperspectral imaging systems also have several disadvantages. They pose considerable computational challenges due to the large volume of data generated, which requires advanced processing and storage capabilities. Image acquisition and analysis can be time-consuming, limiting their efficiency in high-throughput applications. Additionally, the spectral data often contain a series of successive overlapping bands, which can complicate data interpretation and require sophisticated algorithms for accurate analysis.

Hyperspectral imaging has emerged as a rapid and efficient tool for analyzing the quality of food products. It is ideal for contemporary food sectors because to its capacity to offer accurate, non-destructive, and chemical-free measurements. Texture, maturity, and nutrient content are just a few of the quality qualities that can be thoroughly evaluated thanks to the technology. It improves food rating accuracy by gathering both spatial and spectral information. Additionally, it facilitates automatic classification and grading, which lessens the need for human inspection. It also presents the possibility of real-time processing line monitoring. Its benefits exceed its disadvantages, even with some restrictions like high processing requirements and complex data. Thus, it is highly recommended that hyperspectral imaging be widely commercialized and used in food systems.

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