Chapter 1

Introductory Chapter: Trends on Hyperspectral Imaging Development

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1. Introduction

Hyperspectral imaging (HSI) is the set of activities by which images are captured and spectral radiance values assigned to each pixel through the range of wavelengths of the electromagnetic spectrum under visible and infrared regions. HSI sensors provide information on hundreds of narrow wavelength bands of composite. The pixels are sorted and characterized using statistical analysis and software to classify among groups of pixels. The data from each wavelength band are connecting into a three-dimensional hyperspectral (data hypercube) for processing and analysis. Hypercube is composed of layers, and each layer represents data at a specific wavelength. HSI is quite important in food quality and assurance, agricultural practices and environmental quality.

2. HSI in assurance of food quality

Nowadays, consumers are interested in food quality and safety assurance. Fruits and vegetables can be inspected in-line by HSI for increasing the quality and safety of food products but also to offer significant earnings to food processors [1]. Spectral variations due to morphological changes of most fruits and vegetables decrease the prediction of models; in addition, the interferences that specimens possess might affect the classification accuracy, therefore imaging techniques in dealing with morphological effects are needed. Another demand is the automatic recognition of representative region of interest based on computer software to improve model efficiency. HSI systems with low-cost and fast-detecting properties are provided [2]. An effective pixel-based apple bruise region extraction method has been proposed to obtain the complete bruise region. The hyperspectral images of 60 apples were obtained at 0, 12, and 18 h during an experiment. Principal component analysis (PCA) eliminates repetitious data of hypercubes. Random Forest (RF) model obtained high and steady classification accuracy. The mean accuracy of bruise extraction models reached 99.9 [3]. Color parameters (L*, a* and b*), firmness, and soluble solid content (SSC) have been quantified by HSI in the visible and near infrared (VNIR) regions between 600 and 975 nm and the short wave near infrared (SWIR) region between 865 and 1610 nm. SSC can be exactly predicted by SWIR hyperspectral imaging with than 0.8, while L* and a* adjusted better with VNIR hyperspectral imaging displayed correlation coefficients greater than 0.7 for [4]. Near infrared (NIR) hyperspectral imaging can classify among maize kernels of varying hardness and between fungal infected and sound kernels [5].

For the quick and nondestructive detection of microbial decay in muscle of beef, pork, poultry, fish, and so on, techniques have been used such as visible and near-infrared spectroscopy, Fourier transform infrared spectroscopy, fluorescence spectroscopy, Raman spectroscopy, and hyperspectral imaging. When those techniques are combined with chemometric analysis, spectral preprocessing and modeling methods are successfully developed for the determination of total viable count, aerobic plate count, *Enterobacteriaceae*, *Pseudomonas*, *Escherichia coli*, and lactic acid bacteria loads in muscle [6].

Starch content in adulterated fresh cheese has been measured using HSI. In a research, adulterated fresh cheese was prepared using concentrations of starch of 0.055–12.705 mg g^{-1}; afterwards, HSI images in the range of 200–1000 nm, distributed in 101 bands were acquired. A partial least square regression (PLSR) model of starch content was obtained with a determination coefficient (R^2) of 0.9915 and a root mean square error of cross-validation (RMSECV) of 0.3979. With five variables, a correlation coefficient of validation (r) of 0.8321 and a mean square error prediction (RMSEP) of 1.3515 was found for a reduced model [7].

Haugh unit (HU) index is a measure of the quality of the albumen in various studies on egg quality. HU is a destructive test of specimen and correctly reflects the batch of eggs being processed. In a study, fresh eggs were stored at 25°C and measured after storage for 0, 4, 7, 10, 14, 18 and 21 days by HSI system in the wavelength range of 900–1700 nm and compared to HU for each egg. A calibration model for HU initially used PLSR and then cross-validation was performed and a coefficient of determination (R^2) of 0.91 and root mean square error of calibration (RMSEC) of 4.58 was obtained; however, displayed colors of acquired image of eggs were different correspond to the freshness of the eggs based on HU [8].

Dairy product companies are demanding systems for quantifying and qualifying differences between milk powders. Hyperspectral imaging (HSI) has been used to distinguish between milk powders manufactured in factories and of differing practical and useful qualities, for instance, dispersibility. HSI and multivariate analysis techniques such as principal component analysis (PCA) and partial least squares (PLS) regression were performed. The PCA results exhibited differences in the first and second principal components. The PLS technique showed that HSI information could be used to forecast the dispersibility parameter and then establish significant correlations between hyperspectral images and crucial quality attributes of milk powder either on, or at line in close to real time [9].

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Herbal tea demand is increasing because of consumers coming to know of its health benefits. Chromatographical techniques require destructive sample preparation using solvents; therefore, HSI could be a nondestructive alternative method. In a research, HSI pushbroom system captured images of the raw material and tea blends by SisuChema SWIR (short wave infrared). Subsequently, the images were analyzed using multivariate analysis software. PCA revealed 54.2% chemical variation between *S. tortuosum* and *C. genistoides* raw materials. A partial least squares-discriminant analysis (PLS-DA) model had confidence prediction of 95.8% and it was possible to visualize the tea blend constituents (based on pixel classification) as *S. tortuosum* and *C. genistoides* and quantitatively predicted *C. genistoides* as the major constituent (>97%) while *S. tortuosum* was existent in lower amounts (<3%) [10].

Advanced preprocessing methods for denoising that possess high efficiency and high exactitude are appearing to improve the predicting accuracy for using hyperspectral images in food quality evaluation and analysis. Adaptive filters have been developed for applications since they can steadily adjust itself to the changing imaging environment [11]. Hyperspectral pansharpening method has been used with high frequency layer of each band of the hyperspectral image as the guidance image of the guided filter for extraction of spatial details from both the panchromatic image and the hyperspectral image. The total spatial attributes are added in the end into each band of the HS image low frequency layer to generate the last image [12].

On the other hand, hyperspectral fluorescence imaging (HSFI) method has been used to evaluate quality and safety of food since it combines the advantages of both hyperspectral imaging and fluorescence spectroscopy. However, it cannot be said that HSFI is very effective for measuring quality attributes. The potential of this technology for food and agricultural product quality and safety in online inspection will improve rapidly with advances in optical sensing and computer systems [13].

3. HSI in assurance of agricultural practices

The development of hyperspectral imaging systems, both aerial and ground, has been very important in crop monitoring for nutrients, water stress, disease, insect attack and estimation of crop yield in smart agriculture.

The remote perception of water stress in a citrus orchard have been researched using leaf measurements of chlorophyll fluorescence and Photochemical Reflectance Index (PRI) data, seasonal time-series of crown temperature and PRI, and high-resolution airborne imagery [14]. The miniaturization technology has supplied markets with hyperspectral imagers operating on frame format, which is highly attractive for unmanned aerial vehicle (UAV) based remote sensing, because it provides better stability and the likelihood to grab stereoscopic data sets, bringing in a possibility for three dimensional hyperspectral object reconstruction [15]. In some studies, UAV has been performed to acquire RGB images for vegetation analysis [16]. Liquid crystal tunable filter (LCTF)-based hyperspectral imaging system transmitted selected wavelengths without the requirement to exchange optical filters from UAV and measured 14 different ground objects in vegetative areas. Additionally, the machine learning (ML) approach using a support vector machine (SVM) model reached a classification accuracy of 94.5% in vegetated areas [17].

In recent research, automated remote sensing procedures have been developed, assessed, and compared based on novel, low-cost HSI system for the identification of beetle infestations in barks at the individual tree level in urban forests achieving an overall accuracy of 81% (kappa: 0.70), compared to the aircraft results of 73% (kappa: 0.56) in a smaller sub-area [18].

4. HSI in assurance of environmental quality

HSI is rapidly becoming a key tool for pollution tracking changes in the environment. Hyperspectral microscopy (HM) has been explored for nanotoxicity studies of materials in a more native state and truer to conditions of biomedical pertinence. Additionally, HM had potential and found its earliest macroscopic applications in geologic surveying. However, analysis of air or water samples is constrained by the challenge of immobilizing particles [19]. A study based on Hyperspectral Imaging (HSI), was developed to establish an efficient method to characterize marine microplastic litter. Reliable information on abundance, size, shape and polymer type for the whole ensemble of plastic particles in each sample was retrieved from hyperspectral images [20]. A new algorithm has been evaluated using the Hyperspectral Imager for Coastal Ocean (HICO). The hyperspectral vicarious calibration was applied to HICO, showing the validity and consistency of HICO's ocean color products [21]. HSI can arrange pixel providing a lot of potential for material characterization. A study demonstrated that HSI is possible for recognition of pigments [22]. Modern studies of heavy metal pollution of soils have been focused on the hyperspectral reflectance of typical metals in soils and in plants measured either *in situ* or in the laboratory. Most of these studies used wavebands lie within the visible near infrared range of the spectrum, especially the red edge. Metals detection must rely on their co-variation with the spectrally responsive metals or organic matter in the soils [23].

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