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***Abstract*— During the past few decades a number of different techniques have been explored as possible instrumental methods for quality evaluation of food products. In recent years, hyperspectral imaging technique has been regarded as a smart and promising analytical tool for analyses conducted in research, control, and industries. The main impetus for developing a hyperspectral imaging system was to integrate spectroscopic and imaging techniques to enable direct identification of different components and their spatial distribution in the tested sample. The need for fast and reliable methods of authenticity and object identification has increased the interest in the application of hyperspectral imaging for quality control in the agricultural, pharmaceutical, and food industries. So, the aim of this paper was to give brief introduction to hyperspectral imaging system. The first step of the study consists of fundamentals, characteristics, configuration, terminologies, merits and demerits, limits and potential of hyperspectral imaging. The second step presents potential applications of hyperspectral imaging in food analysis.**

***Keywords*— Computer vision, food quality, multivariate analysis, spectroscopy.**

I. Introduction

QUALITY is a key factor for modern food industry because the high-quality of product is the basis for success in today's highly competitive market. In the food industry, the quality evaluation still heavily depends on manual inspection, which is tedious, laborious, and costly, and is easily influenced by physiological factors, inducing subjective and inconsistent evaluation results. To satisfy the increased awareness, sophistication and greater expectation of consumers, it is necessary to improve quality evaluation of food products [1]. If quality evaluation is achieved automatically, production speed and efficiency can be improved in addition to the increased evaluation accuracy, with an accompanying reduction in production costs.

In the light of providing a more consistent and objective evaluation of fruit quality, optical approaches, such as machine vision and spectroscopy, are considered as the most potential methods complementary to the human inspectors on the automatic fruit sorting line [2]. Machine vision has success in categorizing fruits with respect to size, color and other appearance indices. However, its capacity for detecting surface defects is still limited and often not reliable [3], [4]. Spectroscopy has been involved in the food research for dozens of years. Common applications have included not only the quantitative prediction of chemical properties of agricultural products [4]-[8], but also the classification of samples into different classes [9], [10]. However, since spectroscopy generally measures an aggregate amount of light reflected or transmitted from a specific area of a sample (point measurement), it does not contain spatial information about the product.

As a rapid, economic, consistent and even more accurate and objective inspection tool, Hyperspectral imaging have been used increasingly in the food industry for quality evaluation purposes [11]. Hyperspectral imaging is a technique that combines conventional imaging and spectroscopy to acquire both spatial and spectral information from an object. Because of this combined feature of imaging and spectroscopy, hyperspectral imaging can enhance and/or expand our capability of detecting some chemical constituents in an object as well as their spatial distributions. The data collection and processing are, however, still time-consuming, which make it at this moment impractical for being used on line as such. Reference [12] suggested wavelet transforms to shorten the computation time and to reduce the storage space required. Another approach to make this technique feasible is to establish a multispectral imaging system based on the analysis of hyperspectral images. This can be done by selecting several optimal filters for the camera or Light Emitting Diode (LEDs) for the illumination, which correspond to the relevant wavebands for the measurement of the property changes of fruits.

During the last decade, considerable research effort has been directed at developing hyperspectral imaging for food quality evaluation. Reference [13] recently developed a new hyperspectral imaging-based spatially resolved method for

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rapid, non contact measurement of the optical properties of turbid materials over the visible and shortwave near-infrared region. The aim of this paper is to investigate fundamentals and the recent applications of hyperspectral imaging in image processing for food quality evaluation. Although this paper focuses on food quality evaluation, the techniques discussed are of relevance to the wider research topic of image processing.

II. MATERIALS AND METHODS

A. Fundamental of hyperspectral imaging

Hyperspectral imaging is the combination of two mature technologies: spectroscopy and imaging. In this technology, an image is acquired over the visible and near-infrared (or infrared) wavelengths to specify the complete wavelength spectrum of a sample at each point in the imaging plane. Hyperspectral images are composed of spectral pixels, corresponding to a spectral signature (or spectrum) of the corresponding spatial region. A spectral pixel is a pixel that records the entire measured spectrum of the imaged spatial point. Here, the measured spectrum is characteristic of a sample's ability to absorb or scatter the exciting light.

B. Hardware

A hyperspectral imaging system in line-scan mode (also called pushbroom mode) generally consists of four basic components: illumination, an imaging spectrograph, a camera (CCD or CMOS) and a zoom lens. Figure 1 shows the schematic diagram and hardware components of the hyperspectral imaging system is used for measuring the spatial distribution of diffuse reflectance.

C. Image calibration

Hyperspectral image calibration is required to account for spectral and spatial variations in light source intensity, detector response, and system optics. Calibration of spectral response can be achieved using narrow-band light sources (e.g. laser 'pen lights') or calibrated standard reference materials such as NIST (National Institute of Standards and Technology) glasses, and this calibration should be verified periodically. Spatial calibration over the field of view of the HSI instrument should be carried out using a spatially and spectrally homogeneous sample (e.g. flat ceramic tile). Intensity calibration is required to compensate for changes in the detector response and should be carried out using certified reference standards (e.g. Spectralon grayscale standards). Development of suitable reflectance standards and use of correct calibration transformations remains a challenge in hyperspectral imaging. Spatial and intensity calibration should, at the very minimum, be carried out on a daily basis as small changes in electrical power sources, illumination, detector response and system alignment may result in significant changes in the detected response. Inclusion of internal reference standards in each hyperspectral image acquired is recommended; this is also a good way to monitor the performance of the system over time.

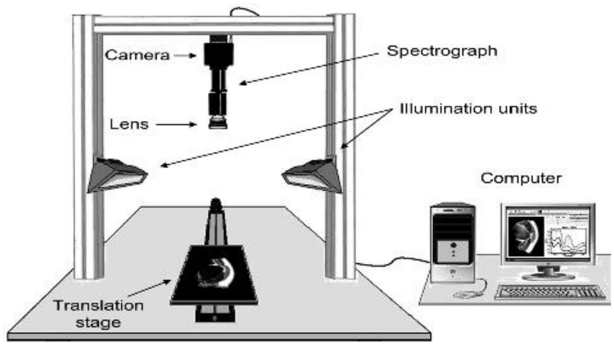

Fig. 1. Configuration of the hyperspectral imaging system.

D. Image processing

Images from different planes in a hypercube may be combined using algorithms based on straightforward mathematical operators, e.g. addition, subtraction, multiplication and division. Image processing is also carried out to convert the contrast developed by the classification/regression analysis into a picture depicting component distribution. Greyscale or colour mapping with intensity scaling is commonly used to display compositional contrast between pixels in an image. Image fusion or false colour mapping, in which two or more images at different wavebands are represented as red, green, or blue channels and combined to form a new RGB image may be employed to enhance apparent contrast between distinct regions of a sample.

E. Hyperspectral imaging software

Many software tools have been developed for hyperspectral image processing and analysis. One of the most popular, commercially available analytical software tools is the Environment for Visualizing Images (ENVI) software (Research Systems Inc., Boulder, CO, USA) which is widely used in food engineering [14]-[20]. ENVI is a software tool that is used for hyperspectral image data analysis and display. It is written totally in the interactive data language (IDL), which is based on array and provides integrated image processing and display capabilities. ENVI can be used to extract spectra, reference spectral libraries, and analyze high spectral resolution images from many different sensors.

MATLAB (The Math-Works Inc., Natick, MA, USA) is another widely used software tool for hyperspectral image processing and analysis, which is a computer language used to develop algorithms, interactively analyze data, and view data files. MATLAB is a powerful tool for scientific computing and can solve technical computing problems more flexibly than ENVI and faster than traditional programming languages, such as C, C++, and Fortran. This makes it more and more popular in food engineering [14]-[21]. The graphics features which are required to visualize hyperspectral data are available in

MATLAB. These include 2-D and 3-D plotting functions, 3-D volume visualization functions, and tolls for interactively creating plots.

III. Results and Discussion

In the last part of this paper, some fundamental concepts about hyperspectral/mutispectral imaging were investigated. As the second part, this paper introduces latest investigative and exploratory studies in major areas that have been impacted by this technique include meat, fruit and vegetables, and others. Tables I and II summarize main hyperspectral and multispectral imaging applications in the area of safety and quality evaluation of food and agricultural products.

TABLE I
HYPERSPECTRAL IMAGING APPICATIONS FOR FOOD AND AGRICULTURAL PRODUCTS

Class	Product	Application	Reference
Fruits and Nuts	Apple	Firmness evaluation	[22]
	Walnut	Shell and meat differentiation	[23]
	Citrus	Rottenness detection	[21]
	Citrus	Canker detection	[20]
	Banana	Quality and maturity evaluation	[24]
Vegetables	Tomato	Ripeness evaluation	[25]
	Cucumber	Quality evaluation	[26]
	Mushroom	Bruise detection	[27]
	Onion	Sour skin disease detection	[28]
	Potato	Cooking time prediction	[29]
Meat	Chicken	Skin tumor detection	[30]
	Pork	Quality evaluation	[19]
	Fish	Moisture and fat evaluation	[31]
	Beef	Microbial spoilage detection	[32]
	Lamb	Lamb type discrimination	[33]
Grains	Corn kernel	Constituent evaluation	[34]
	Wheat kernel	Sprout damage detection	[35]
	Corn kernel	Aflatoxin detection	[36]
Beverages	Milk	Fat content evaluation	[13]
	Tea	Quality classification	[37]
	Milk	Melamine detection	[38]

TABLE II
MULTISPECTRAL IMAGING APPICATIONS FOR FOOD AND AGRICULTURAL PRODUCTS

Product	Application	Wavelength (nm)	Reference
Tomato	Maturity evaluation	530, 595, 630, 850	[39]
Apple	Defect and feces detection	530, 665, 750, 800	[40]
Chicken	Wholesomeness inspection	580, 620	[41]
Tea	Category sorting	580, 680, 800	[42]
Peach	Maturity evaluation	450, 675, 800	[43]

Commercial hyperspectral/multispectral imaging systems for food and agricultural applications [e.g., Hyperspec Inspector produced by Headwall Photonics (Fitchburg, MA, USA) and SisuCHEMA produced by Specim (Oulu, Finland)] started appearing on the market in recent years. Such integrated systems generally include essential components in a whole package (e.g., light source, wavelength dispersive device, camera, embedded computer, hard drive, and software) for implementation of spectral imaging techniques. The commercialization of the spectral imaging systems will broaden the scope of the applications for food safety and quality evaluation.

Recent works show a bright future of using hyperspectral imaging for the quality inspection of more and more food products. The successful outcome of applying hyperspectral imaging would improve quality and safety measurement of finfish products to meet consumer expectations, label accurate quality factors on the packaging of retail products to benefit consumers, and help the food industry to better understand and control the food quality and safety, leading to increased competitiveness in international markets. However, there are still some limitations and restrictions to be overcome for hyperspectral imaging before move this technology from the laboratories to the industry real-time inspections, including improving the hardware and software of hyperspectral imaging system to reduce the instrument cost and increase the measurement speed, extracting the most important object features from hyperspectral images to develop feature based imaging systems like multispectral imaging, investigating the most suitable model calibration strategy with high accuracy, efficiency, and robustness for the inspection, and transferring the systems and algorithms, which are dependent on the laboratory environment to industrial conditions.

IV. Conclusion

This paper reviews the recent developments in Hyperspectral techniques for the agricultural and food industry. Hyperspectral techniques have been used increasingly in industry for assessment and estimation purposes as they can provide rapid, economic, hygienic, consistent and objective assessment. Hyperspectral imaging is an important analytical technique widely used in the agro-food industry applications for quality organization and food safety inspection, in that it exploits the optical properties of materials for quality assessment. Hyperspectral imaging and imaging spectroscopy have own advantage of extracting spectral information from a larger area of the specimen to give more minute and detailed information from the whole specimen. These techniques especially hyperspectral imaging require high speed computer and large memory to save the bulky data. Furthermore using high-speed computer with an advanced processing and image acquisition system, the hyperspectral imaging technique presents a lot of prospects for automated quality classification of food products.

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