March / April, 2004

Hyperspectral Imaging for Nondestructive Assessment of Fruit Quality

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Appearance, texture, and flavor are three most important quality components for fresh fruit. Appearance gives us the first impression about the quality of fruit but it is texture and flavor that ultimately determine consumer satisfaction. Currently, technologies for sorting fruit for appearance (i.e., color, size and/or shape) are widely adopted in the United States and other industrialized nations. But appearance such as color is not a reliable indicator of flavor and texture. Technologies that can measure important quality attributes of fruit nondestructively would provide the fruit industry with a means to deliver superior quality, more consistent fresh products to the consumer and greatly improve the industry's ability to meet consumer demands for fruit quality.

Considerable recent research has been focused on using optical techniques to measure internal quality of fruit. Near-infrared spectroscopy (NIRS), which measures diffusely reflected or transmitted light over a range of invisible wavelengths longer than the visible light, has been used for predicting the sweetness of apples and other fresh fruits. Commercial application of NIRS for sorting apples and other fruits for sweetness has started recently. There are, however, still considerable technological challenges for measuring firmness and other quality attributes of fresh fruit.

When a light beam is incident upon a fruit, some will be absorbed and some will be scattered in the form of either backscattering reflectance or transmission. Absorption and scattering are two basic phenomena as light interacts with a scattering object. Light absorption is related to certain chemical constituents such as sugar, water, and chlorophyll. Scattering, on the other hand, is associated with the structural features of fruit and, hence, it may be useful for measuring the textural properties of fruit. If both absorption and scattering can be measured, more information about the chemical (such as sugar, acid, etc.) and physical (such as firmness) properties of fruit may be obtained.

CONCEPT OF HYPERSPECTRAL IMAGING

Digital imaging is now ubiquitous from scientific research to our personal daily life. Conventional imaging (such as personal use digital cameras) produces two-dimensional images, which are obtained by capturing broadband light reflected from the object. In the case of color imaging, images are actually composed of three broadband colors ? red, green, and blue ? since all colors can be created from these three basic colors. In many scientific and industrial applications, we need to know more detailed information about products other than surface color and texture. Conventional imaging often cannot ascertain or detect minor or subtle features and constituents of the products because these chemical constituents are only sensitive to specific wavelengths. That is the reason why spectroscopy technology such as NIRS is very useful for chemical analysis and measurement. NIRS 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.

Hyperspectral imaging is a technique that combines conventional imaging and spectroscopy to acquire both spatial and spectral information from an object. Hyperspectral imaging produces three-dimensional images or hyperspectral image cubes. The third dimension contains spectral (or wavelength) information for each pixel on the hyperspectral image cube. 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. Hyperspectral imaging has been used in a wide range of scientific and industrial fields including space exploration; remote sensing for environmental mapping, geological search or mineral mapping, atmospheric composition analysis and monitoring, military target detection or recognition; precision farming; and medical diagnosis. Hyperspectral imaging has also found its application for food quality evaluation and safety inspection.

FRUIT QUALITY ASSESSMENT

We have developed a hyperspectral imaging system, which acquires spectral and spatial information from fruit simultaneously over the visible region and part of the near-infrared region (Fig. 1). The system mainly consists of an illumination unit, an imaging spectrograph with a zoom lens, a scientific grade charge-coupled device (CCD) camera, and a computer. The imaging spectrograph is an optical device that separates polychromatic light into individual wavelengths while preserving its spatial information. The illumination unit generates a sharp, focused white light beam. As this light beam hits the fruit, it penetrates into the fruit tissue; photons are either scattered or absorbed. The backscattered light illuminates a portion of the fruit contiguous and adjacent to the incidence area, generating a scattering image at the surface of the fruit (Fig. 2). The hyperspectral imaging system is used to capture this scattering image from the apple fruit for wavelengths over the visible and near-infrared region.

We developed computer algorithms to extract useful information from fruit scattering images and then relate this information to fruit internal quality attributes such as firmness and sugar. As such, hyperspectral images are first compressed by mathematical methods to reduce the data size and enhance image features. Important features are then extracted and input into an artificial neural network (ANN). ANNs are inspired by the way human neural systems are organized and operated; they possess the ability of learning or modeling any nonlinear relationship and self-adapting. After the ANN is properly trained, it will be able to predict firmness and sugar of other fruit.

Over the past two years, we have tested the hyperspectral imaging system for measuring apple fruit firmness and sugar content. The system gave good predictions of fruit firmness with the correlation coefficient greater than 0.8 and of sugar content with the correlation of 0.9. With these encouraging results, we further developed a prototype multispectral imaging system, which acquires scattering images at several selected wavelengths simultaneously (Fig. 3). The prototype system is now being tested and evaluated for real time measurement and grading of fruit based on firmness and sugar. We will continue to improve and refine the system so that it can meet the online sorting requirements for apples and other fruits.

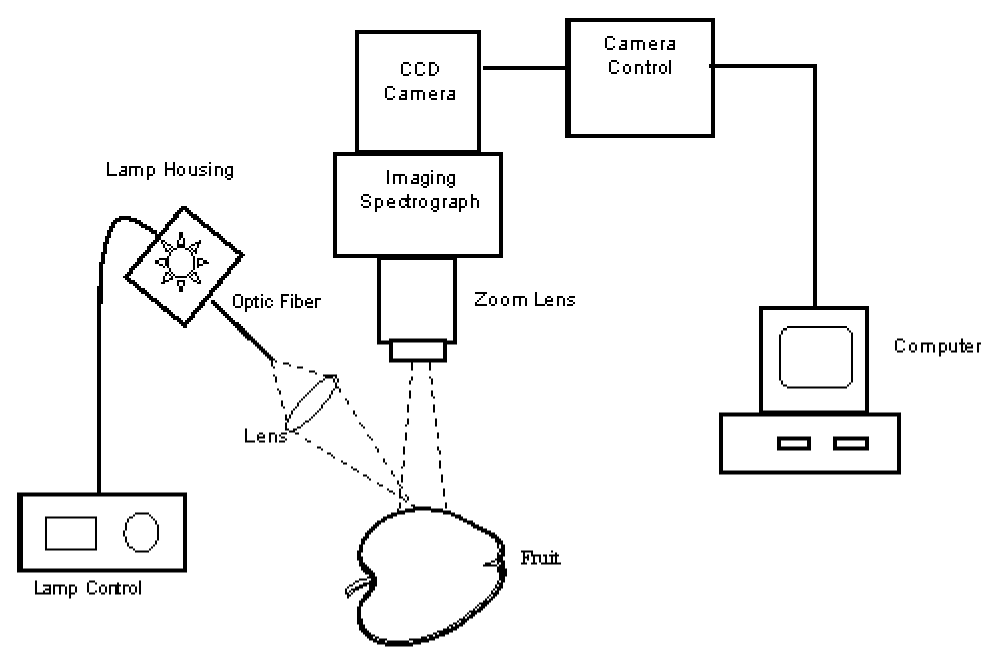

Figure 1. Schematic of a hyperspectral imaging system for measuring the scattering profiles of apple fruit.

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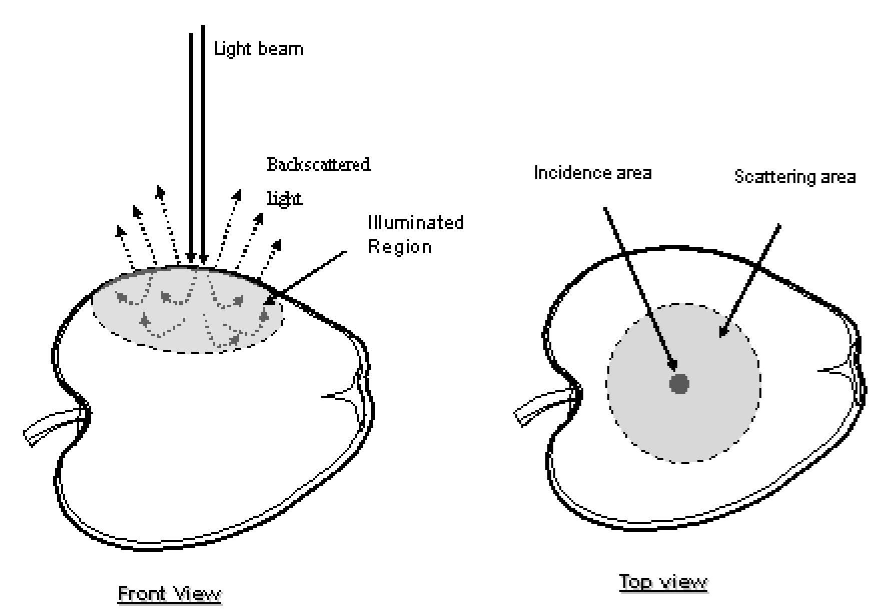

Figure 2. Concept of measuring hyperspectral scattering in apple fruit.

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Figure 3. A laboratory multispectral imaging prototype for real time sensing of apple fruit quality.