Hyperspectral Scatter Imaging for Contactless Food Quality Evaluation
Chyngyz Erkinbaev, Mizuki Tsuta, Nghia Nguyen Do Trong, Pieter Verboven, Bart Nicolaë, Josse De Baerdemaeker, Wouter Saeys

ABSTRACT
In food process engineering there is a need for non-destructive, fast and accurate techniques for online quality inspection. Spectroscopy based methods are already used by the industry for non-destructive internal quality analysis of food. However, these techniques require contact with the sample surface, therefore in this research a hyperspectral scatter imaging technique has been elaborated to perform contactless spatially resolved diffuse reflectance spectroscopy for estimation of optical properties of selected biological materials. These optical properties then can be correlated to the actual quality attributes with respect to chemical and physical properties of food material. Three dimensional hypercubes with two spatial and one spectral axis are constructed from the images of apple fruits acquired with the hyperspectral scatter imaging set up. The optical properties were estimated from the scatter images using an inverse light propagation model for selected wavelength bands. Preliminary results showed that the hyperspectral scatter imaging technique can be used as a contactless, rapid and accurate method for on line quality determination of agricultural and food products.

Keywords: hyperspectral scatter imaging; apple; absorption coefficient; scattering coefficient.

INTRODUCTION
Postharvest and food process engineering refers to the sorting, grading, processing, packaging, storing and transporting of food and agricultural produce. Sorting and grading operations are main process units, which determine the product quality during technological processes. Determination of the main quality attributes of food is traditionally performed destructively and these time consumable methods require sample preparation and use of chemicals. Therefore, the food industry demands for accurate, rapid, non-destructive and inexpensive methods for food quality and safety control.

Optical measurement techniques, such as Visible and Near Infrared spectroscopy are now widely used as non-destructive methods in monitoring of the properties of agricultural products such as fruits, vegetables, cereals, etc [1, 2]. However, these methods are often not robust in complex biological materials, due to the complex interaction of incident light with food involving both absorption and scattering of the light. These spectral data calibration techniques can not provide information on light scattering and absorption in quantitative base. The light scattering is primarily due to physical characteristics (e.g., particle size, cellular structure, density), whereas light absorption is related to the chemical constituents (e.g., protein, fat, carbohydrates). These two optical properties are characterized by the absorption coefficient ($\mu_a$) and reduced scattering coefficient ($\mu_s$) [3]. Determination of these optical properties for food products can be used for better understanding composition/structure relationships. Estimation of these properties could be done by time or space resolved multiple measurements of the light intensity changes through the sample [3, 4]. In spatially resolved spectroscopy, light of constant intensity illuminates the sample and multiple detectors at different distances are used to record the scattering profile of the light. This method is rapid and less complicated compared to the time resolved and frequency domain approaches which are far more expensive. Spatially resolved spectroscopy has been extensively studied in biomedical applications using fibre optic probes. However, this approach is less applicable for online sorting and inspection of food products, because of the need for contact with the product and the desired measurement speed. Another approach of the spatial resolved spectroscopy can be a hyperspectral scatter imaging technique in which two spatial dimensions can be obtained for multiple spectral range.

Therefore, the hyperspectral scatter imaging technique has been elaborated to perform contactless spatially resolved spectroscopy. This technique allows determination of the optical properties of food and agricultural products from light scattering profiles acquired with a hyperspectral imaging system.
Hyperspectral scatter imaging techniques for the measurement of optical properties of food products are not well developed and only limited research has been reported on quality estimation of fruits and vegetables [5-7].

In this research the potential of hyperspectral scatter imaging for the contactless characterization of microstructure and composition properties of fruit samples has been investigated.

**MATERIALS & METHODS**

*Hyperspectral scatter imaging system*

A hyperspectral scatter imaging setup has been developed for contactless determination of spatially resolved profiles from selected fruit samples. Generally, the system consisted of a CCD camera (KP-F120, Hitachi, Ontario, Canada) with optical sensitivity from 400-1000 nm and 1392 by 1040 pixel image resolution, a prism-grating-prism-based imaging spectrograph (ImSpector V10, Spectral Imaging Ltd., Oulu, Finland) covering the spectral range between 400 and 1000 nm, a focusing lens, a light source with a tungsten halogen lamp (Alphabright, East Succex, UK) coupled into a fiber with collimating lens (Ocean Optics, Duiven, Netherlands), and a controlled moving stage with an adjustable sample holder. The system was operated using LabView V8.5 (National Instruments, Austin, TX, USA). The schematic view of the hyperspectral imaging setup is presented in Figure 1. The hyperspectral imaging system operated in push broom scanning mode. The hyperspectral imaging system was spectrally calibrated using spectral calibration cube (Zeutec, Rendsburg, Germany) with Mercury and Argon lamps with known peaks at certain wavelengths, the geometrical calibration was done by scanning millimetre paper.

![Figure 1. Schematic illustration of the Hyperspectral Scatter Imaging System.](image1.png)

![Figure 2. Procedure for optical properties determination.](image2.png)

The broadband light source was collimated into a 1.0-1.5 mm diameter beam projected as vertically as on to the sample surface. For each pixel in the scanned line the light that was diffusively reflected by the sample surface onto the slit of the spectrograph was dispersed into different wavelengths, which were then projected onto the CCD detector to create a 2D reflectance image with spatial and spectral dimensions. A hyperspectral scattering image of 700x520 pixels was obtained, which had a spectral resolution of 1.31 nm/pixel and a spatial resolution of 0.02 mm/pixel. In order to limit the calculation speed the images were binned to reduce the number of wavelength bands to 260, corresponding to a spectral resolution of 2.3 nm/pixel.
Samples

Sixty apples of Braeburn cultivar were supplied by the Flemish Centre for Postharvest Technology (VCBT). The samples were divided into two set (bad and good cultivation) for optical properties estimation and destructive measurements (total soluble solids and firmness). The experiments were done for 30 apples just after harvesting and for 30 apples after storing at optimal conditions for 14 days. Each apple was scanned on two positions close to the equator, the distance from the camera to the sample was kept constant by adapting the height of the sample holder.

Determination of optical properties

The spatially resolved profiles of apple fruits were extracted from hypercubes and then were smoothed by Savitzky-Golay filter with window size of 11 nm, second order polynomial and represented for one specific wavelength in Figure 4. Optical properties (absorption coefficient $\mu_a$ and reduced scattering coefficient $\mu_s'$) of apple fruit samples were estimated from spatially resolved hyperspectral scatter images for selected wavelengths using diffusion theory model [8, 9]. The algorithm for determination of the optical properties is illustrated in Figure 2. The optical properties estimation algorithm was developed and implemented in Matlab (version 7.5, The MathWorks Inc., Natick, USA).

RESULTS & DISCUSSION

Hyperspectral reflectance images

The hyperspectral reflectance image acquired for a Braeburn apple is presented in Figure 3. The spatial distribution of the reflectance with increasing distance from the illumination spot is illustrated in Figure 5 for three selected wavelengths (650, 750 and 900 nm). These profiles are different for each wavelength, because the optical properties of the sample are wavelength-dependent. For example, the reflectance values at 650 nm are considerably lower, because of light absorption by chlorophyll. The spatially resolved reflectance profiles were also found to be clearly different for hard and soft apple fruits. This might be attributed to differences in the scattering properties due to differences in the microstructure.

Figure 3. Hyperspectral scatter image of apple fruit: (a) 2D image (b) 3D profile.
In Figure 6 the absorption coefficient values are presented for two apples with clearly different hardness. This absorption coefficient has strong relationship with chemical composition, because the chemical bonds of biological components absorb light energy at specific wavelengths, resulting in so called “fingerprints”. In the 500-600 nm range the soft apple gave slightly higher absorption values, while the absorption in the 650-670 nm range was considerably higher. This can be explained by the higher chlorophyll content in a less mature (harder) apple.
The overall pattern of the absorption coefficients of apple fruit obtained in this study by hyperspectral scatter imaging is generally in agreement with reported results for various fruit and vegetable samples [6]. Incident light on fruit surface has more scattering interaction in short wavelength than longer wavelength, more detailed studies should be done on interpretation of multiple scattering phenomena.

CONCLUSION

A hyperspectral scatter imaging system was developed in the laboratory and its potential for contactless quality estimation of complex food products has been illustrated. The optical properties estimation algorithms should, however, be validated on optical phantoms, optically designed homogeneous material with known absorption and scattering properties, to allow interpretation of the absolute estimated values. Preliminary results showed that the hyperspectral scatter imaging technique can be used as a contactless, rapid and accurate method for on-line quality determination of agricultural and food products.

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