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Proceeding Paper

Near-Infrared Wavelength Selection and Optimizing Detector Location for Apple Quality Assessment Using Molecular Optical Simulation Environment (MOSE) Software †

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Abstract: As an alternate non-destructive analytical modality for monitoring from pre-harvest to post-storage, optical imaging with near-infrared wavelength is used to forecast the quality of numerous fruits. In the near-infrared spectrum, bio-chemicals are identified and measured with light by penetrating deeply into food components. In addition, apples and other fruits with a high water content benefit from water absorption capabilities. The optical approaches are efficient, inexpensive, and environmentally beneficial. This study is performed to examine the setup of reflection imaging to pick the near-infrared wavelength and optimize the distance between the detector and the light source. Molecular Optical Simulation Environment (MOSE) and Monte Carlo multi-layered programs (MCML) were used to simulate the light propagation in a model of apple tissue to select the appropriate wavelength for evaluating food quality in experiments and optimize the position of the reflected signal receiver. As a consequence, the 700–900 nm wavelength has great promise for use in assessing food quality, particularly apple quality. One centimeter is the optimal distance between the detector and the light source. The data may be used to organize an experiment and create an evaluation tool for determining the quality of fruits using optical methods, particularly apples.

Keywords: optical imaging; light propagation; near-infrared; Monte Carlo; MOSE; MCML

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1. Introduction

Methods of nondestructive food quality evaluation based on optical features have been an increasing trend in fruit quality testing. As a result of the complexity of light propagation in multilayered food tissue, the optical assessment of food quality confronts several problems. The light propagation model using the Monte Carlo simulation (MC) approach is a typical and effective tool for gaining a deeper comprehension of the interaction between tissue and light. Moreover, in recent years, the modeling of light propagation in foods such as apples, onions, and citrus fruits has been investigated more extensively to anticipate their optical characteristics [1–3]. It provides guidelines for improving systems and creating noninvasive optical technologies for assessing food quality.

Light transmission through opaque tissues, such as fruit, is complex and is related to absorption and scattering of photons. Therefore, an understanding of optical characteristics

is necessary to better comprehend the light-tissue interaction or to enhance nondestructive assessment methods. This research is carried out for the propagation of light in apples between 500 and 1000 nm with the Monte Carlo method. In this investigation, the simulation model is spherical. The light source is positioned at a certain distance from the surface of the sample. The purpose of this research is to analyze backscatter pictures using a simulated Charge-Couple Device (CCD) to determine the optimal probe location.

2. Materials and Methods

2.1. Monte Carlo Method

Radiative Transfer Equation describes the transmission of light in opaque tissues such as fruit (RTE). The RTE equation is used to represent the propagation of light in turbid media and light's wave qualities, such as diffraction and interference. There are several ways to solve RTE equations, including analytical and numerical approaches. However, the MC simulation approach is considered the standard for resolving this radiation transport issue due to its simplicity. Moreover, determining the appropriate inaccuracy to decrease computational effort is simple [4,5].

The MC approach enables simulating the transport of radiation in an opaque model based on the likelihood of a mean free route whose direction changes owing to Fresnel reflection scattering, and absorption. The probability relies on optical characteristics such as the scattering coefficient μ_s the absorption coefficient μ_a, and refractive index n, the anisotropic scattering coefficient g. The chemical makeup of opaque tissue is primarily responsible for its ability to absorb light. On the other hand, light scattering in tissue is dependent on the structural characteristics of the propagation medium (density, particle size) and the cellular structure [6].

2.2. Simulation Model

To run the simulation, the model needs geometrical parameters and optical qualities. In this study, the Monte Carlo Multi-Layered (MCML) program and the Molecular Optical Simulation Environment (MOSE) tool are used to simulate the Granny Smith apple [7,8]. The radius of the simulated apple sample model is 2.5 cm. The optical characteristics in Table 1 are derived from the research conducted by Cen et al. [9]. In addition, the Granny Smith sample's refractive index n and anisotropic scattering coefficient g are 1.35 and 0.80, respectively [6]. At MOSE, the acquisition of the reflected signal is mimicked by the default setup of the Charge Coupled Device (CCD). The resolution of the acquisition is 512 by 512 pixels.

Table 1. Inputs for MCML and MOSE simulation.

Parameter	Value
Photon	1,000,000
Resolution of radial distance *dr*	0.01 cm
Resolution of tissue depth *dz*	0.01 cm
Number of grids for radial distance r	500
Number of grids for tissue depth z	500
Refractive index for medium above/below (air)	1.0
Radius of the light beam ($1/e^2$ radius)	0.15 cm

3. Results and Discussion

3.1. Penetration Depth

Extremely dense materials prevent the transmission of light. Instead, the photon packet is separated into tissue absorption, diffuse reflection, and specular reflectance [10]. In the simulation model, photons penetrate to a maximum depth of about 3.0 cm at all wavelengths, as seen in Figure 1.

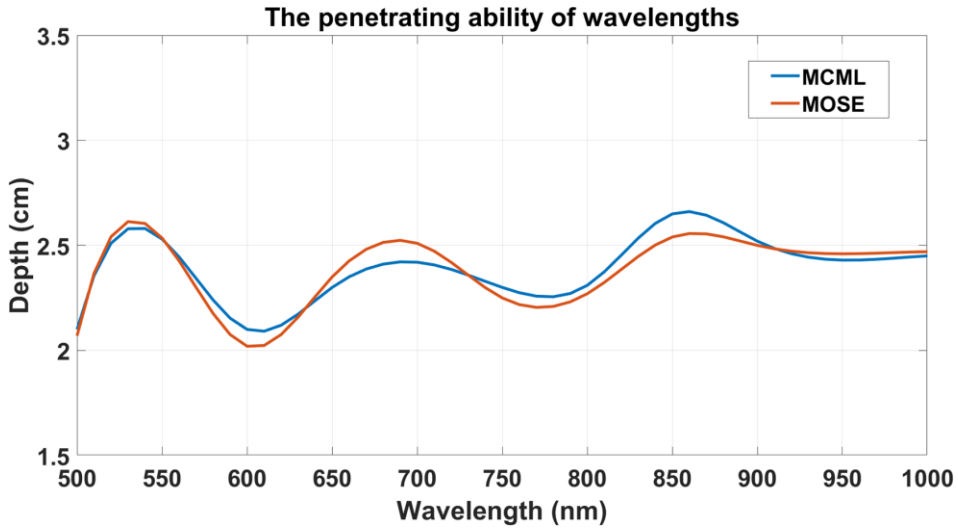


Figure 1. Penetrating ability of wavelengths.

As illustrated in Figure 1, 500–1000 nm wavelengths may profoundly enter apple tissue via absorption and scattering. However, it is difficult to transmit these wavelengths. As a result of the characteristics of the apple's optical properties, a high incident light intensity in transmittance is necessary for light to pass through the whole fruit. Due to the high power consumption in transmittance mode, the light may harm the apple's surface and affect the spectral properties. Several studies have referenced this material [3,10,11]. In the light-based approach for non-destructive quality evaluation, the reflection mode has more promise than the transmission mode.

3.2. Diffuse Reflection

Figure 2 shows the diffuse reflectance spectra of a simulated apple model throughout the wavelength of 500–1000 nm. The diffuse reflection is weakest at 650 nm wavelength and brightest at 750 nm. The optical properties of the simulated apple model at various wavelengths are characterized by the variation in diffuse reflectance at different wavelengths. As a result of the interior composition of apple tissue, high internal absorption occurs at 600 nm, absorbing the majority of photons, while mild absorption occurs at 750 nm.

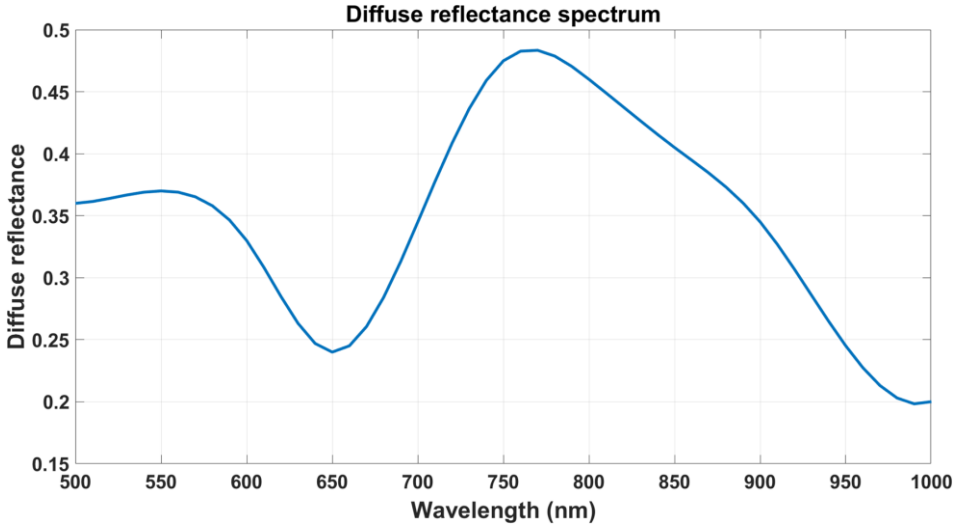


Figure 2. Diffuse reflectance spectrum.

3.3. Optimizing Source-Detector Distance

The distance between the source and detector is optimized with a wavelength of 750 nm. As demonstrated in Figure 2, this wavelength has more benefits than other wavelengths. Therefore, it gives additional information for evaluating apple quality. The diffuse reflection of radius r at 750 nm as simulated by the MCML software (version 1.2.2) is seen in Figure 3.

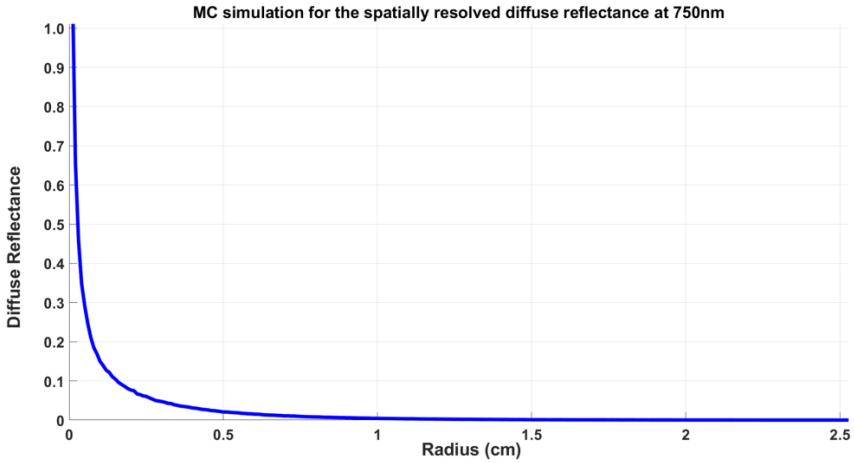


Figure 3. Diffuse reflectance at 750 nm.

Attenuation of the obtained diffusely reflected signal diminishes with increasing distance, with the strongest signal received at a distance of 0.0 cm (or close to the surface). In practice, it is altered by the light source diffusing straight into the detector. The acquisition of a diffusely reflected signal is deemed appropriate within a radius of 1.0 cm. After a radius of 1.0 cm, the reflected signal begins to degrade and provides insufficient data for assessment.

3.4. Back-Scattering Image by MOSE

Figure 4 depicts the simulated back-scattering picture and intensity profile generated by the MOSE program. As illustrated in Figure 5, the program is produced when the light source is positioned in the middle of the CCD. In this arrangement, the light source and CCD detector are simulated to be 1.0 cm from the surface of the apple. However, this setup is not working.

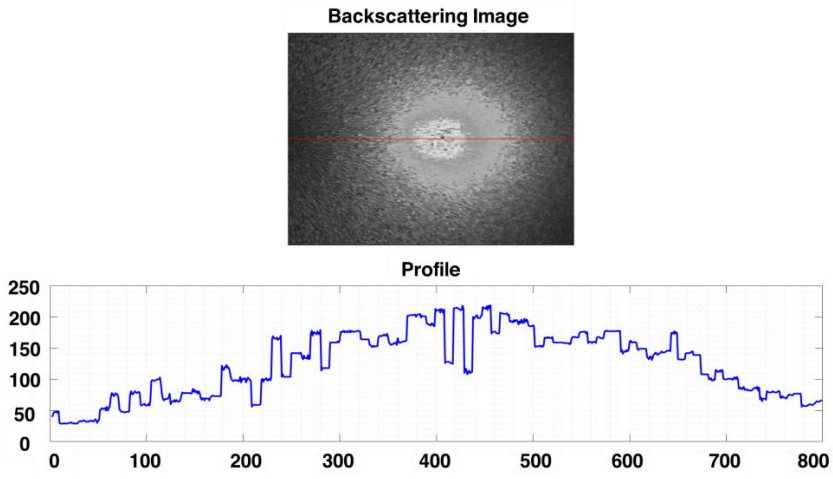


Figure 4. Simulated back-scattering image and its profile along its center.

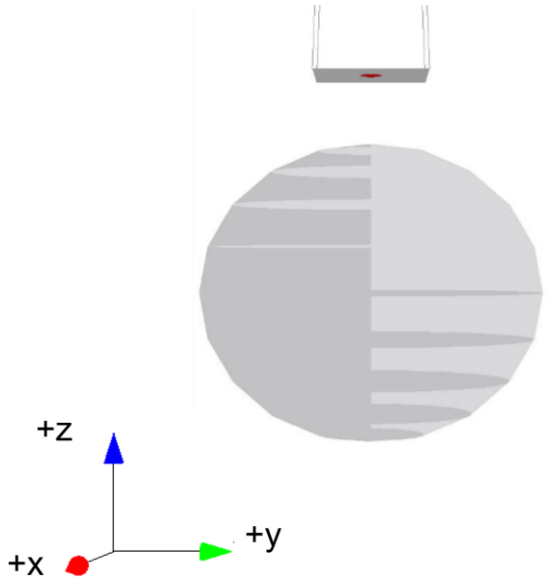


Figure 5. Light source (red dot) is placed at the center of the CCD detector.

Figures 6–8 illustrate the outcome of varying the distance between the light source and the CCD detector while maintaining the same arrangement as Figure 5.

When the distance of the light source from the center of the CCD detector is set as 0.9 cm, Figure 6 depicts the simulated back-scattering picture and its profile along its center.

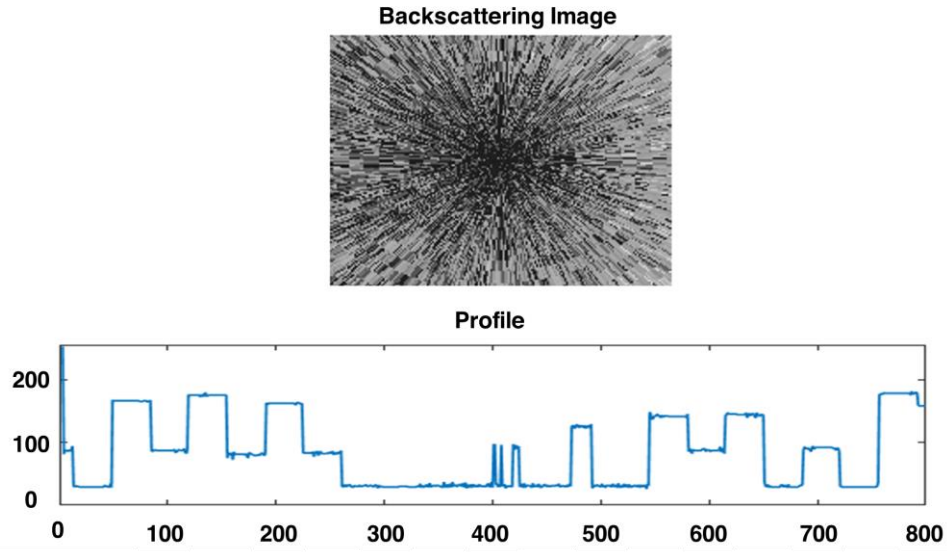


Figure 6. Simulated back-scattering image and its profile along its center (source-detector distance is 0.9 cm).

When the light source is situated 2.0 cm from the center of the CCD detector, Figure 7 depicts the simulated back-scattering picture and its profile along its center.

Figure 8 depicts the simulated back-scattering picture and its profile along its center when the light source is situated 3.0 cm from the CCD detector's center. As seen in Figures 7 and 8, a design with a source-detector distance of less than 1.0 cm provides a greater signal-to-noise ratio and more information.

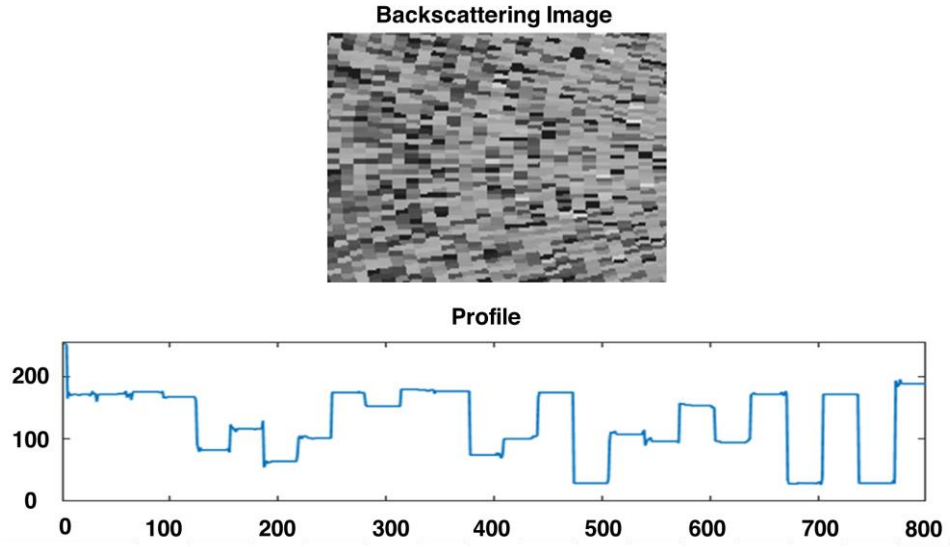


Figure 7. Simulated back-scattering image and its profile along its center (source-detector distance is 2.0 cm).

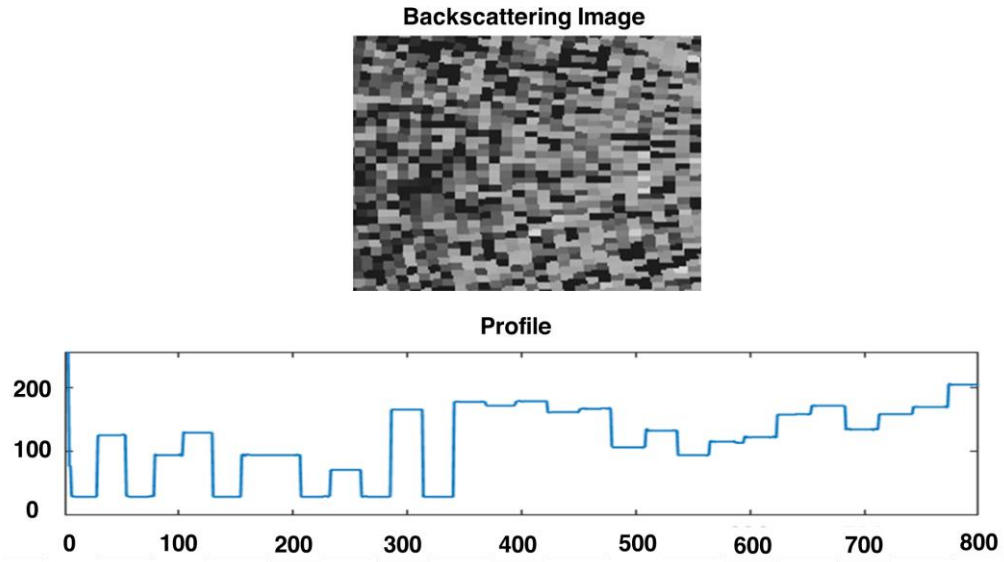


Figure 8. Simulated back-scattering image and its profile along its center (source-detector distance is 3.0 cm).

4. Conclusions

We study light propagation through a model of apple tissue using the Monte Carlo simulation approach and the MCML and MOSE programs. In the MOSE model, the Granny Smith apple was represented as a 3D spherical model. The findings of the simulation demonstrate that light cannot flow through the model. The result demonstrates that the reflection mode is superior to the transmission mode in the visual evaluation of food quality. The diffuse reflectance spectral band has the highest reflectivity at 750 nm. Therefore, it is recommended to utilize it to build a nondestructive optical method for assessing food quality. The optimal positioning of the detector probe is less than 1.0 cm from the light source. The arrangement with a source-detector distance of less than one centimeter may provide more data and a greater signal-to-noise ratio.

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