Two-layer Model for Measuring the Optical Properties of Turbid Materials Based on Spatially Resolved Hyperspectral Diffuse Reflectance Images

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1. Introduction

Hyperspectral imaging-based spatially resolved technique is useful for determining the optical properties of fruits and food products that are homogenous. To better characterize fruit properties and quality attributes, it is desirable that fruit be considered as two homogeneous layers, i.e., skin and flesh. This research was aimed at developing a nondestructive method to determine the spectral absorption and scattering properties of two-layer turbid materials with characteristics of fruit.

2. Materials and methods

A two-layer diffusion model was used to describe light propagation in layered biological materials [1]. An inverse algorithm was developed for extraction of optical properties from the spatially resolved diffuse reflectance acquired by a hyperspectral imaging system. Sensitivity coefficients were calculated to analyze the response of reflectance to perturbations in values of optical parameters [2]. Monte Carlo (MC) simulations [3] and experimental data from model samples with known optical properties were performed to validate the model and inverse algorithm.

3. Results and discussion

Based on the four selected combinations of optical properties, the magnitudes of the reduced scattering sensitivity coefficients were almost equal to that of reflectance (R), while the sensitivity coefficients of absorption were relatively smaller but still on the order of R for some distances. It was also noted that the shapes of the four sensitivity coefficients were quite different. These observations showed that sensitivity coefficients of the optical parameters were ‘large’ (i,e. on the order of R) and uncorrelated (different shapes), which were desirable conditions for estimating these parameters.

The same sets of optical properties were used to generate reflectance profiles from the two-layer diffusion model and MC simulations. The differences of reflectance were less than 6% for source-detector distance greater than 1.5 mm. It indicated that the diffusion model accurately quantified light propagation in two-layer turbid media. Optical parameters of the two layers were estimated using the proposed inverse algorithm with the diffusion model fitted to the MC generated reflectance data. The average errors of determining two and four optical parameters were 6.8% and 15.3%, respectively.

The reflectance profiles extracted from the hyperspectral images of the two model samples at selected wavelengths were in good agreement with the theoretical predictions that were calculated from the diffusion model. Absorption and reduced scattering coefficients of the first layer for the two model samples were estimated. The errors were 11.3-23.0% for absorption coefficients and 3.8-18.4% for reduced scattering coefficients. The results were worse than those obtained from MC simulations due to larger uncertainties in the experimental data.

4. Conclusions

This research demonstrated the feasibility of evaluating the optical properties of two-layer turbid materials, characteristic of the skin and flesh of fruit, using a two-layer diffusion model for spatially resolved reflectance acquired by a hyperspectral imaging system. The two-layer diffusion model accurately described light propagation in two-layer turbid media as shown by good agreement of the results with those generated by MC simulations, and the inverse algorithm gave better estimates of optical parameters for MC generated reflectance data than those for experimental data. Further research is needed to optimize the hyperspectral imaging system in order to achieve more accurate reflectance measurement for two-layer turbid materials.

5. References

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