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Investigation of light propagation in pork tissue applied in multispectral imaging technique by Monte Carlo simulation method

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Abstract

Despite the limited knowledge of light propagation in foods, optical techniques are becoming more common in the evaluation of food quality. Using the Monte Carlo technique, we model light propagation in pork tissue in this research. Since then, researchers have been examining how light moves through pork tissue and how multispectral imaging methods may use this information. Light can penetrate deep into the food tissue in the range of wavelength examined in this paper. The purpose of this study is to simulate the signal reception, select the appropriate wavelengths and the signal acquisition mode. The simulation results offer a general structure for system design and the creation of optically based food quality assessment tools.

1 Introduction

The demand for food quality assessment has been increasing in recent years, resulted in the development of food quality assessment techniques, especially non-invasive assessment methods because of the advantages such as fast, wide applicability... [1]. Thereby, optical-based methods offer a great deal of potential for evaluation, which includes two main techniques of "point" measurement and multispectral or hyperspectral methods to be applied over wide parts of the food surface based on the VIS-NIR wavelength range [2]. In this research, the multispectral imaging method is mainly focused.

Despite the complexity of food tissues, which makes it difficult to fully apprehend how light interacts with them, research into the use of optical technique in food has long been of interest [3]. Additionally, a potent tool for supporting such investigations is the Monte Carlo simulation technique.

In order to learn more about how light penetrates pork tissue, we have simulated it using the Monte Carlo simulation approach in the wavelength range of 650 nm to 900 nm. The results of this analysis are focused on the development of experimental models, including simulations of signal acquisition, wavelength, and appropriate signal acquisition mode,... in the evaluation of quality by the multispectral imaging method.

2 Materials and Methods

2.1 Light interaction with food materials

Optical techniques in food quality assessment are generally based on the interaction of light with food tissue. Within the VIS-NIR region of the electromagnetic spectrum, food tissue (in this research, pork) is considered a turbid medium. [3]. It consists of two major optical phenomena, absorption, and scattering. In which, absorption is mainly by chemical components of tissues (pigment, water, ...) and scattering is caused by physical factors such as microparticles inside the medium. Therefore, when light interacts with food tissue, common phenomena include reflection (at the surface - specular reflection or diffusion), absorption, transmission via [4]

Based on those factors, there are two main modes in assessing food quality including reflectance mode and transmittance mode. [5]. In addition, there is an interactive mode, but because of the complexity of setting up experimental and simulation models to capture only diffuse reflected signals, it is not mentioned in this research.

2.2 Monte Carlo Method

The propagation of light into turbid media such as food or human tissue is described based on the radiation propagation equation (RTE) and is simplified to the diffusion equation (DE). [3, 6]. In particular, light propagating in a medium is considered only as a collection of photons (particle properties), ignoring wave properties of light such as interference, diffraction, or polarization... [6]. There are various ways to solve RTE equations, including numerical or analytical methods, but those methods take time. The Monte Carlo approach is regarded as the best method for solving RTE equations because it can reduce computing burden and determine the required error. [7].

The transportation of photons in an opaque medium based on the RTE equation is characterized by the fundamental optical properties of absorption, scattering and refraction and is determined by the absorption coefficient (μ_a), scattering coefficient (μ_s), refractive index (n), and anisotropy factor (g) [7].

2.3 Simulation Model

In this research, we conducted a light propagation model in pork tissue consisting of only one layer of meat (muscle) based on Molecular Optical Simulation Environment (MOSE) software developed by Ren et al. [8] combined with the Monte Carlo Multi-Layered (MCML) program programmed by Wang et al [9]. Figure 1 shows the simulation model at MOSE in which the dot is the light source at the center, the box is the simulated pork model, and the square is the ROI of the simulated CCD receiving the signal.

We also built a model of receiving and receiving reflected and transmitted signals using the default simulation CCD in the program with the resolution set to 512 x 512 pixels.

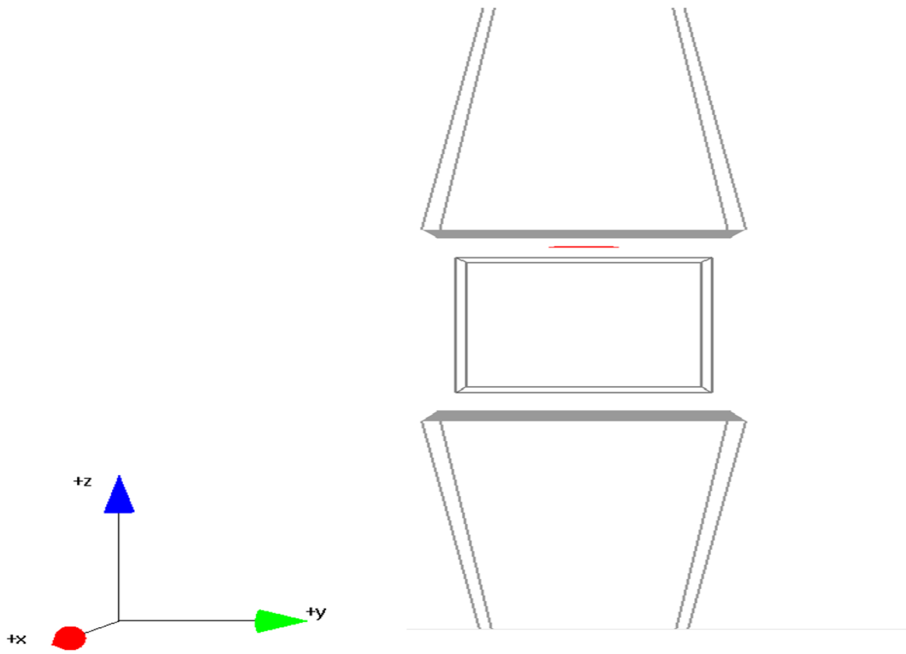

Figure 1: Simulation Model.

3 Results and Discussion

3.1 Penetration depth

In the simulation model of light propagation in turbid media, only a small fraction of photons are able to propagate out of thick tissues, most of the photon packets are absorbed and scattered inside the tissue due to the properties of chemistry and physics of the tissue, a small part will be reflected at the tissue surface according to Fresnel's law of reflection [10]. In the simulation results of this research, most of the photons were absorbed and scattered inside the pork tissue at the wavelength range of 650-900 nm as described in Figure 2.

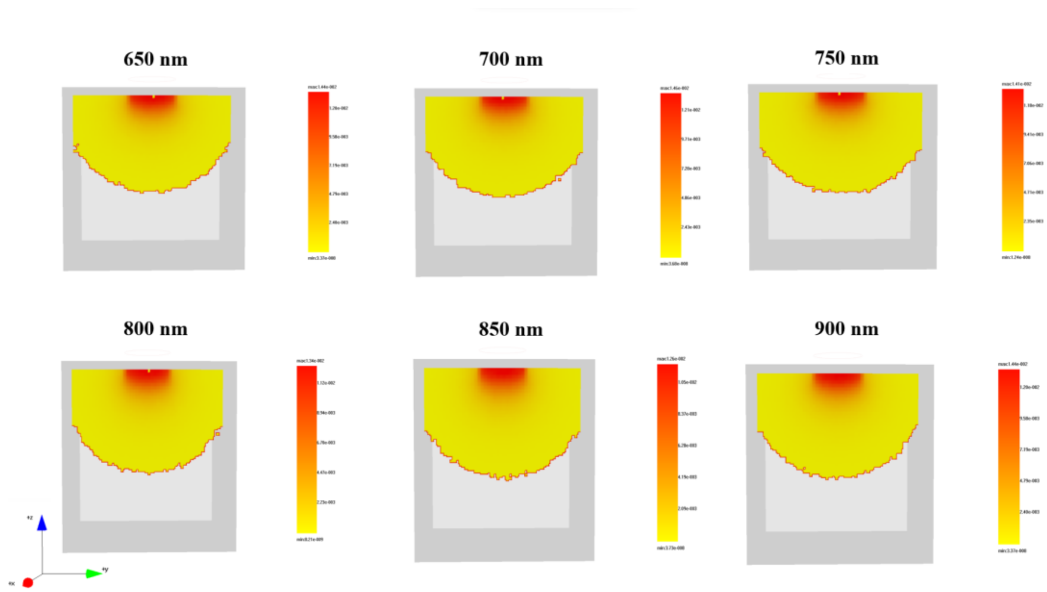

Figure 2: Penatrating ability of wavelenghts.

In the examined wavelength range of 650 - 900 nm, most of the photons are absorbed in the mid-tissue in the range of 2.4 - 2.6 cm, of which the 700 nm wavelength has the deepest penetration at 2.6 cm. The explanation for this is due to the strong absorption and scattering of the components inside the pork tissue at 700 nm, which makes the photons able to penetrate deep into the pork tissue.

3.2 The Reflection

Figure 3 shows the diffuse reflectance spectrum of the simulated pork model in the wavelength range from 650 - 900 nm by MCML program.

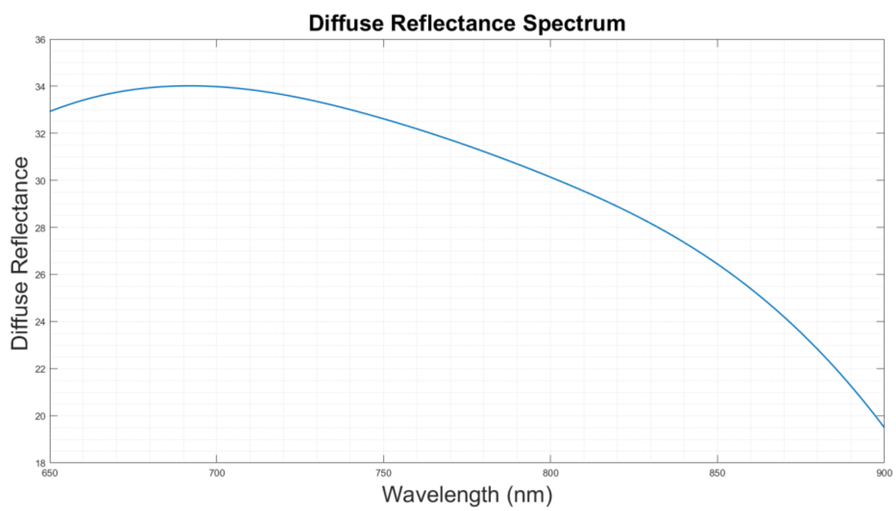

Figure 3: The diffuse reflectance spectrum.

In the diffuse reflectance spectrum shown in Figure 3, the diffuse reflectance ratio is different at each wavelength, with the highest at about 700 nm and the lowest at 900 nm. The reason for this difference is in absorption and scattering properties at each wavelength in pork tissue, specifically, the difference between the optical parameters at each wavelength for surveyed meat tissue.

Similar to Figure 3, the diffuse reflection at the surface of the simulated pork model is shown in Figure 4.

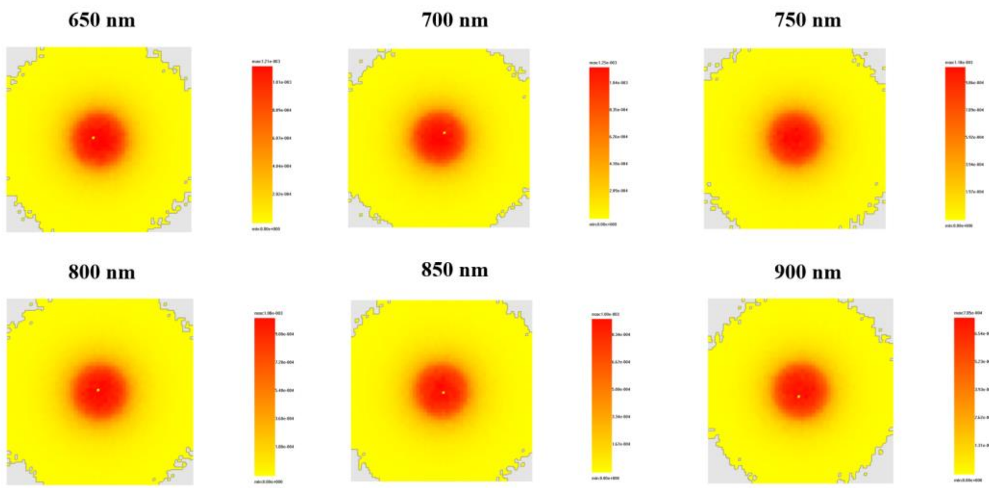

Figure 4: The reflectance at the surface.

The diffuse reflection at the surface is shown in Figure 4, at each wavelength, the diffuse reflection at the surface is also different, in which at 700 nm the surface reflection takes place strongly. and at 900 nm this reflection is weakest.

3.3 The signal acquisitions

Based on the above results, the 700 nm wavelength demonstrates potential for use in studies evaluating food quality in pork. Therefore, we simulate the signal acquisition by CCD camera in a simulated pork model based on MOSE software in both reflected and transmitted modes at 700 nm. Figure 5 shows the signal acquisition in the reflection mode (a) and transmission mode (b) at 700 nm.

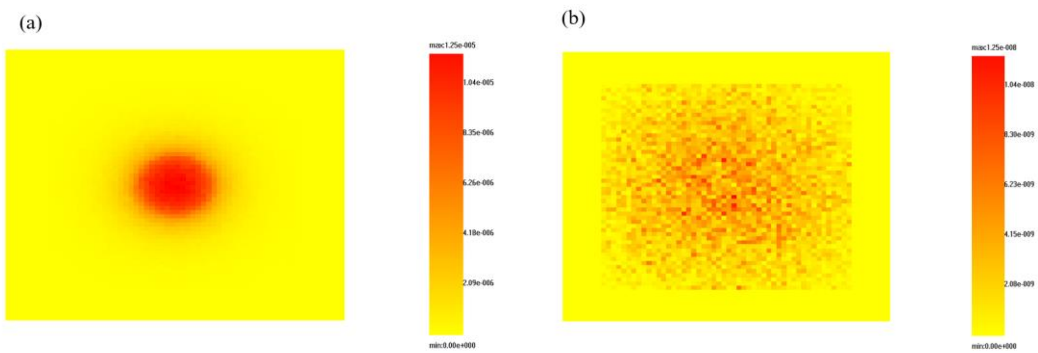

Figure 5: The signal acquisition by CCD Camera at 700 nm (a) reflectance mode and (b) transmission mode.

Figure 5 demonstrates that the reflected signal acquisition is entirely captured, with the signals being concentrated in the surface's center by the light source there. The outcome is comparable to the signal acquisition. In Figure 4, the surface-reflected signal is shown. As a result of the majority of photons being absorbed and reflected in the medium simulated field, relatively few photons can escape into the environment, which causes the transmission mode signal acquisition to only occasionally receive the signal. As a result, signal processing finds it difficult to determine the meat's quality. The intensity of the incident light source must be increased to properly receive the sent signal, but doing so damages the sample's surface and alters the sample's internal characteristics. Several additional papers on the use of light in evaluating food quality make reference to this as well. [11]. Therefore, it can be concluded that the acquisition of the reflected signal in the thick meat sample model holds more potential in practical applications and in the design of evaluation experiments than in the transmission method.

4 Conclusion

Research on the application of optical techniques in food quality assessment is becoming more and more popular, especially based on multi-spectral image acquisition techniques. In this research, we simulated the propagation of light in pork tissue in the wavelength range from 650 - 900 nm to comprehend the propagation of light in this medium, thereby directing further research in constructing experimental models.

The results indicate that the 700 nm wavelength has the advantage of being used for evaluation in pork because of its penetrating and reflective capabilities. At this wavelength, light can propagate deep into the meat sample and reflect outward well, so this light carries a lot of information about the texture and content of substances inside the food. has great potential for application in multispectral techniques to evaluate pork quality. In addition, we proceeded to use a simulated CCD camera to receive signals in both reflection and transmission modes and concluded that it is easier to receive reflected signals in the design of experiments in evaluation, especially for thick meat samples.

This research provides an overview of studies using light in pork quality assessment, especially multispectral imaging techniques. Based on the simulation of light propagation in biological tissue (in this research, pork) to understand the interaction between light and food tissue, thereby designing experiments used in food quality assessment based on optical engineering or in research and fabrication of devices used to assess the quality of pork meat.

The authors declare no conflict of interest.

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