SIMULATIONS AND EXPERIMENTS OF PHOTON PROPAGATION IN BIOLOGICAL TISSUE AND LIQUID CRYSTAL WAVEGUIDES

Abstract

by

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The development of non-invasive methods to probe human tissue is an ongoing challenge in biomedical optics. *In vivo* measurements by conventional methods are limited by the mean free path (MFP) of a photon, which is governed by the spatial distribution of chromophores and the absorption and scattering properties of the tissue. As one of the strongest chromophores in human tissues, hemoglobin concentrations in human tissue greatly affect the MFP of photons in visible wavelengths (i.e. bruising). Changes in the concentration of hemoglobin and other chromophores within the tissue (minor trauma causing a contusion, increased bilirubin due to jaundice, etc.) will affect the MFP, leading to a visibly different appearance (color) of the tissue. As color perception is a complex physiological process, these changes are difficult to quantify by human observation alone. The transport of hemoglobin and its breakdown products in tissue is related to a number of medical conditions that could benefit from a non-invasive method to determine the hemoglobin levels.

Chapter 1 identifies efforts to quantify the interaction of light with tissue in an effort to discern meaningful information about the tissue structure and chromophore concentrations therein. Colorimetry, hyperspectral imaging, and single-point diffuse reflectance spectroscopy are explored. Identifying a need for a mathematical model to gain a better understanding of the interaction of light within the tissue, a novel

Monte Carlo technique for 3D photon tracking is presented.

Chapter 2 explores the application of this model to the conjunctiva. Anemia affects almost 3.5 million Americans, with millions more being undiagnosed, making it the most common blood disorder in the U.S. Anemia is characterized by abnormally low hemoglobin levels and is generally identified by a complete blood count test. The Monte Carlo model is employed to simulate reflectance spectra of the conjunctiva for a non-invasive tool to determine hemoglobin levels. Simulated results are compared to experimentally obtained data.

Chapter 3 explores the application of the model to contused skin. Medical expertise is frequently elicited to aid in determining the age and the cause of the trauma or injury. Child protection and law enforcement frequently rely on the physical assessment of the trauma which involves delineating intentional from unintentional types of trauma. By combining reflectance spectroscopy measurements with the Monte Carlo model, it is possible to determine the concentrations of hemoglobin and its breakdown products in the tissue, which may lead to the development of a non-invasive medical device to determine the age of a bruise. Simulated results of normal and contused skins are compared to experimentally obtained data.

Chapter 4 explores the application of the model to a previously uninvestigated (for optical properties) tissue system, the placenta. Twin-twin Transfusion Syndrome is a rare condition wherein identical twin fetuses develop connected blood vessels with the tissue (∼4,000 cases in the U.S. annually). Severe cases result in an unbalanced flow from one fetus to the other and will have a 90% mortality rate if left untreated. Treatment requires endoscopic surgery where the surgeon visually inspects that surface of the placenta to identify connected vessels which are then laser ablated (via fiber optic probe). Researchers at Brown University investigated the use of reflectance spectrometry to determine hemoglobin levels to aid in identifying connected vessels. The model is employed to determine hemoglobin levels and to explore the unknown optical properties of the tissue with results compared to the clinical data.

Chapter 5 focuses on the use of liquid crystals in spectrometry. A review of current research on liquid crystals highlights the use of liquid crystals as tunable reflective/transmission filters. A prototype liquid crystal tunable filter for use within a hand-held spectrometer is presented.

The Appendix offers a brief report on the use of liquid crystal (LC) waveguides that do not require an electric field to change the transmission properties. Instead, two films are used and the arrangment of one film with respect to the other will alter transmission. Just as having two linear polarizers together and rotating one of them will vary the transmission properties, the linear displacement of one patterned LC film with respect to the other will result in the same performance.