Monte Carlo simulation of diffuse reflectance spectra for quantitative assessment of physiological properties of human skin

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Presently, the optical to near-infrared spectral characterization of biological tissues are of a considerable interest in frame of new sensors development. The theory of radiation transfer deals with the diffuse intensity of light and is widely used for description of light-tissue interaction. Due to the complex structure of tissue and, respectively, boundary conditions, one of the most popular solution of radiative transfer equation is the stochastic Monte Carlo (MC) technique. It has been shown that MC approach can quite realistically imitate the propagation of light within biological tissues.

We utilize unified object oriented MC model, developed in-house, which allows describing photons and structural components of biological tissues as the objects interacting to each other. Thus, the core of our modeling methodology is focused on the computational observation of how an object-photon propagates through an object-medium and interacts with its constituents, mimicking in such way an interaction with cells, blood vessels, collagen fibers, etc. Such a representation of the medium by objects makes it possible to develop comprehensive 3D tissue models with the required spatial variations of malformations. To achieve the optimal modelling performance, we use a parallel computing framework CUDA (NVIDIA Corporation).

In particular, for the simulation of skin diffuse reflectance, we have developed a seven-layer tissue model. The model takes into account the absorbing and scattering properties of the skin. Absorption coefficients of the layers are calculated by taking into account concentration of blood volume fraction in skin, blood oxygen saturation, hematocrit, water content, melanin fraction, and fat content. The scattering coefficient of a particular layer is represented by a combination of Mie and Rayleigh theories. The model also takes into account the anisotropy factor and the refraction index of the layers.

The developed approach was successfully applied for hyperspectral assessment of physiological properties of the skin. To solve the inverse problem of estimation of skin chromophore content, a neural network approach was used. A training set of spectra for the neural network was modelled by the MC method. The combination of a fast hyperspectral camera, neural network-based processing and MC simulation allowed for multiparameter estimation of tissue properties. The devel-oped technique has potential applications in monitoring and diagnostics of diabetic ulcer formation and other relevant skin diseases along with cosmetological defects.