BOOK REVIEW

Biomedical Optics, Principles and Imaging

Lihong V. Wang and Hsin-I Wu, 362 pages +xiv, ISBN: 978-0-471-74304-0, illus., index, John Wiley & Sons, Inc., Hoboken, New Jersey (2007), $90.00, hardcover.

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Lihong Wang and Hsin-I Wu, professors of biomedical engineering with outstanding teaching and research experience, faced a common dilemma: the lack of an appropriate textbook that they could use to teach their biomedical optics courses. *Biomedical Optics, Principles and Imaging* (hereafter called *Biomedical Optics*) is their solution: guided by their extensive pedagogical experience, they expanded their class notes and wrote their own textbook for a one-semester course that contains many worked examples and homework problems.

This is an important and a useful book. While many books on the subject of biomedical optics appear to cover a similar range of topics, there are many lacunae, and the treatment of the subject is often variable and spotty. Many researchers work on the theme of biomedical optics, and at some time they will be required to teach, work with, or understand the fundamental theory and the mathematical formulation of light scattering, light diffusion, and the implementation of the Monte Carlo method to simulate the problems they are attempting to solve. One useful technique is to study the original papers. Another alternative is to study this textbook and work through the sample problems and solutions. The latter suggestion has the benefits of a uniform notation and a coherent and clear exposition. *Biomedical Optics* provides a more comprehensive approach to all of these topics than what is typically found in multiauthor volumes that attempt to cover every aspect of the field.

Biomedical Optics is an expanded version of the authors' class notes, and, therefore, the authors recommend that two semesters are needed to teach the full content of the book. The intended audience is upper class undergraduates and graduate students, as well as scientists, engineers, and clinicians who will use the book as a reference or for independent study. The authors expect that the students will have a background in calculus and differential equations, and they suggest that experience in MATLAB® or C/C^{++} would be helpful.

What is the scope of *Biomedical Optics*? The primary function of the text is to teach the reader how quantitatively to approach the interaction of light and biological tissue. There are two levels to this approach: first, the mathematical description of the fundamental physics, and second, the use of theories and models that approximate the exact theory so that the complex systems can be modeled with computer simulations, and the results can ultimately be compared with experimental measurements. Within the primary function are contained the following general topics: Rayleigh theory and Mie theory, Monte Carlo modeling of photon transport in tissues, radiative transfer, and diffusion theory. The first half of the text is devoted to these topics.

With that presentation of the theoretical background of the subject, the second half of the text describes the important imaging and spectroscopic techniques that the readers of the *Journal of Biomedical Optics* (JBO) have developed and applied to cells, tissues, and organisms. The latter part of the text contains chapters on the following subjects: fluorescence spectroscopy and sensing, ballistic imaging, optical low-coherence tomography, Mueller optical-coherence tomography, diffuse optical tomography, photoacoustic tomography, and ultrasound-modulated optical tomography. Some of these biomedical optical techniques have become extremely useful clinical diagnostic instruments, e.g. scanning laser ophthalmoscopes, confocal dermatoscopes, and microscopes based on low-coherence optical tomography. Clearly, the discussion closely follows the research interests of the authors and some topics are allotted a very brief discussion; e.g., confocal microscopy and multiphoton excitation microscopy are discussed in a few pages. Furthermore, topics that are considered part of the field of biomedical optics, such as optical trapping and manipulation, are not mentioned in the text.

The authors provide the reader with several very useful adjuncts that serve to enhance the utility of this textbook. The integration of the mathematics into the text is very smooth, and therefore the book is very clear. The figures (black and white) are well designed and cleanly printed, which makes them easy to understand. A few of the figures would be more comprehensible if color were used; e.g. some of the two-dimensional reconstructions of the absorption coefficient. In addition, there are tables of experimental data. Throughout the chapters the authors provide worked examples that help the student to understand the details of the mathematical manipulation of the models. The authors frequently provide the reader with MATLAB® scripts. At the end of each chapter there are examples of computer codes and homework problems that supplement the materials covered in the text. Following the problems are two lists of references: labeled reading and further reading. I found the selection of websites, peer-reviewed publications, and books to be very helpful for the reader that is motivated to peruse the original literature. The textbook is complete with an appendix that defines the basic optical properties and the derived optical properties, a list of acronyms, and a detailed index.

Following a brief introduction in which the authors place optical imaging in comparison with other imaging modalities such as x-ray, ultrasound, and magnetic resonance imaging (MRI), the reader is exposed to an in-depth account of light scattering. We often hear the terms Rayleigh scattering and

Mie scattering. Many of the readers of this journal may know that the Rayleigh theory of light scattering is only valid if the scattering particles are much smaller than the wavelength of the incident light; in contrast to that requirement, the Mie theory is valid for spheres of any size as long as they are homogeneous and isotropic. The Rayleigh theory is a subset set of the Mie theory. The readers of *Biomedical Optics* will come to understand the subtleties of both theories: their derivations, the assumptions and approximations that are incorporated into the theory, and the validity of their use. After introducing the various theories of light scattering of small particles, the authors describe the details of Monte Carlo modeling of photon transport in biological tissue.

Many of the readers of JBO use the Monte Carlo method in their research. What is the history of this prevalent technique? The paper by N. Metropolis, "The Beginning of the Monte Carlo Method" (*From Cardinals to Chaos, Reflections on the Life and Legacy of Stanislaw Ulam*, N. G. Cooper, Editor, Cambridge, Cambridge University Press, 1989), provides a brief historical introduction. In Rome, Enrico Fermi was experimenting with various substances that serve as neutron moderators. In the course of this work, Fermi invented, but did not name or publish, what is today the Monte Carlo method. Later, in the United States, Fermi also invented an analog computer (the FERMIAC or Monte Carlo trolley) that was used to solve neutron scattering problems in two dimensions.

In 1946, Stanislaw Ulam devised the Monte Carlo method while he was recuperating from an illness and playing cards. He then made the suggestion to John Von Neumann for a statistical approach based on random number inputs that could be used to study neutron diffusion in fissionable materials and devices. This is a very difficult problem since there are multiple chain reactions related to the escape of neutrons as well as their scattering and absorption (production and loss of neutrons). Von Neumann went on to further develop the modern Monte Carlo method that has proved so robust in solving a variety of extremely complex problems. Initially used to solve problems associated with the development of the atomic bomb, today we see the Monte Carlo technique as a very useful tool in biomedical optics research. An important point to remember is that the technique yields the ensemble average or the asymptotic quantities. Ulam understood the power of the newly invented digital computer and its capability to rapidly implement the Monte Carlo technique. It was Metropolis who gave the name Monte Carlo to the technique. In 1949, Ulam and Metropolis published the first paper on the Monte Carlo technique; they formulated computer algorithms and developed the methods to transform physical problems that appear to be nonrandom into mathematical expressions that are soluble with the statistical Monte Carlo technique. For example, the Monte Carlo method was used to approximate solutions to the Schrödinger equation by Fermi, Metropolis, and Ulam.

The topics of Monte Carlo modeling of photon transport in biological tissue and the radiative transfer equation and photon diffusion theory comprise a significant portion of *Biomedical Optics*. The authors summarize the Monte Carlo method succinctly: "the trajectory of a photon is modeled as a persistent random walk (in a true random walk all the steps are independent), with the direction of each step depending on that of the previous step. By tracking a sufficient number of photons, we can estimate physical quantities such as diffuse reflectance." The authors then proceed to describe how to perform this amazing process under the following limitations: coherence, polarization, nonlinearity, and structural anisotropy. Following an explanation of the flow chart that implements the Monte Carlo algorithm, the authors describe how to obtain physical quantities such as absorption, fluence, total diffuse reflectance, and total transmittance in biological tissues.

Light transport in biological tissues can be described by the use of numerical solutions to the radiative transfer equation using Monte Carlo techniques, or analytically using the diffusion approximation. The latter approach is more readily and rapidly implemented, but the results thus obtained may be less accurate than the Monte Carlo method under certain conditions. The authors provide a clear and detailed presentation of the optical property to be modeled, the steps in the diffusion approximation for a computer simulation, the formulation of the algorithm, and the experimental validation of the calculated results.

The remaining chapters of *Biomedical Optics* cover a variety of imaging techniques that are of interest to the readers of JBO. One chapter describes ballistic imaging and microscopy. The discussion of confocal microscopy and multiphoton excitation are too brief and should be expanded in a future edition. The authors devote almost one half of their book to the topic of tomography that yields three-dimensional images of biological tissues. The other topics that are described include optical low-coherence tomography, Mueller optical-coherence tomography, diffuse optical tomography, photoacoustic tomography, and ultrasound-modulated optical tomography.

I commend the authors for providing the biomedical optics community a textbook and reference book that is both comprehensive and concise. The authors successfully extracted the essential physics and the corresponding mathematical descriptions of a variety of important topics. Although the text is brief, it is clear that the organization, use of computer simulations, problem sets, and judicious selection of references all work together to make *Biomedical Optics* an excellent text.

The authors provide the reader with an analytical framework as well as computer codes that supplement the text and permit the reader to perform computer simulations and derive optical properties of biological tissues. *Biomedical Optics* is not for everyone; however, for the reader with the appropriate mathematical and computational prerequisites, the benefits of studying this book, solving the problems, and employing the computer codes are great. In summary, I highly recommend *Biomedical Optics*.