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Book Review

Adaptive Optics for Biological Imaging

Joel A. Kubby, 359 pages + xvi, ISBN: 978-1-4398-5018-3, CRC Press, Boca Raton, Florida (2013), $99.95, hardcover.

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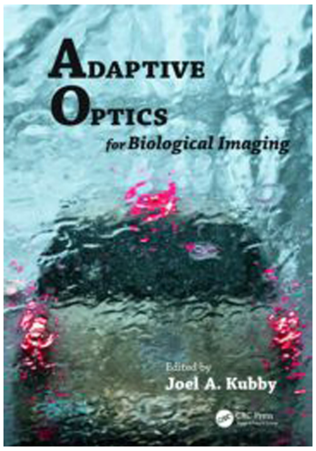

It is fascinating how optical technology transfers among disparate fields of science and engineering. The history of adaptive optics is a good case study. The story begins in 1953 when a visionary, Horace Babcock, who was an astronomer at the Mount Wilson and the Palomar observatories, proposed a method based on adaptive optics to correct in real time the atmospheric distortions that degraded ground-based telescope images. All ground-based telescopes suffer from atmospheric turbulence, which causes time-dependent inhomogeneities in the air refractive index. They are caused by nonstationary random processes. The wind shears mix various atmospheric layers and the temperature inhomogeneities result in time-dependent variations in the refractive index of the air. They distort the wavefronts and thus degrade the image. One alternative is space-based telescopes such as the Hubble Space Telescope. Another is to implement Babcock's idea of a closed-loop system incorporating a wavefront sensor and a deformable mirror that can introduce real-time changes in the wavefront to compensate for the aberrations introduced by the atmospheric turbulence. Babcock's prescient ideas were developed into instrumentation in the mid-1970s and in 1982 the Defense Advanced Research Projects Agency (DARPA) working with the United States Air Force completed a real-time adaptive optics system integrated with an optical telescope on Maui in Hawaii. The motivation was to obtain high-resolution images of Soviet satellites. One common wavefront sensor is the Shack-Hartmann wavefront sensor, which works with white light and also with extended sources (such as the Sun). The closed-loop adaptive optics system involves computer wavefront reconstruction, which is a classical inverse problem whose solution can be found, but the solution cannot be proved to be unique.

The migration of the adaptive optics technology to the fields of ophthalmology and visual science is another fascinating story. Josef Bille at the University of Heidelberg is the visionary physicist credited with translating the astronomical adaptive optics systems to ophthalmology. Recently the European Patent Office selected him as the winner of its lifetime achievement award for his development of wavefront technology for laser eye surgery. Bille mentored many creative graduate students and coworkers who worked on wavefront and laser technologies for biomedical applications. For example, in 1989 Andreas Dreher and colleagues developed a scanning laser ophthalmoscope that incorporated a deformable mirror. In 1991, Bille's graduate student Junzhong Liang published his thesis on "A new method to precisely measure the wave aberrations of the human eye with a Hartmann-Shack sensor." This provided a method for the closed-loop adaptive optics instruments for use in the visual sciences. Subsequently, Liang joined David Williams' laboratory at the University of Rochester and they developed a high-resolution wavefront sensor to measure the aberrations of the human eye, and later together with Donald T. Miller they constructed a high-resolution adaptive imaging system to image the human retina.

Joel A. Kubby edited a comprehensive book that serves as a good introduction to adaptive optics for biological imaging. The book is composed of contributed chapters, many of them based on prior publications, which illustrate both the theoretical background of the field and its fascinating biological imaging applications.

The strength of the book is the delicate balance of theory and instrumentation and applications. For example, the chapter on the design and construction of a confocal microscope that corrects for aberrations will appeal to all of us who design and construct optical imaging instruments. The author begins by stating a series of critical design questions. Once the author formulates the answers to the basic design questions he proceeds to design and construct the instrument. This is a useful and a logical approach to instrument design and development that is often not discussed in publications and books. The author first determines the sources of the optical aberration; which have their origin in the optical system and which are from the specimen. Then the magnitudes of these aberrations are estimated and a design decision is made of which aberrations are important and which can be ignored. The critical author also compared the Zernike coefficients, as measured mean and standard deviations, for several different biological specimens: the mouse oocyte cell, the mouse blastocyst, and the nematode *C. elegans*. Finally the author evaluates the effect of the numerical aperture on the aberrations. The critical discussion of which level of aberrations correction makes sense highlights the thinking of the instrument designer and builder. The lesson that is apparent to the reader is that the optical aberrations in a microscope depend on several factors: the instrument, the specimen, and the numerical aperture of the objective. Therefore, statements about the efficacy of adaptive optics to correct aberration must specify these parameters and meaningful comparisons are only valid between similar systems, objectives, and specimens.

Another example of the comprehensive nature of the chapters is a critical discussion of the adaptive optical elements. John Girkin carefully compares the use of spatial light modulators and deformable mirrors in the design and use of adaptive optics for nonlinear microscopy. The critical comparison of alternative algorithms, wavefront sensors, and other components of an adaptive optical imaging system is unfortunately not contained in all of the book's chapters.

In the course of reading each chapter I detected some errors and misleading sentences. For example, in the chapter on the overview of adaptive optics in biological imaging, the authors confused the cornea and the ocular lens in their introduction to the section on the biological imaging of the eye. I now present a more serious problem with the production and the design of the book that severely impacts its usefulness. The publisher's decision to publish the book with gray-scale figures and a color insert that only contains some of the figures is detrimental to the utility of the otherwise excellent book. I found this to be a distraction during my reading of each chapter; in fact, many of the black-and-white figures are not reproduced in the color insert section. Some of the gray-scale images contain the text "(See color insert)" but there is not a matching color figure. The black-and-white Zernike mode plots are useless and in general the image quality is poor for a book that is about biological imaging. Many of the figures that contain graphs composed of multiple lines are incomprehensible in the small printed format and with their original use of color truncated to poor quality gray-scale images.

Adaptive Optics for Biological Imaging is a good place to start to understand the problem (aberrations induced by the instrument, the objective, and the specimen and its preparation and mounting in the microscope), and the various instrumental and computational approaches to approach a solution (minimize the significant aberrations). The important lesson is that the reader should investigate alternative approaches, understand the limitations of each approach, and make a rational design decision that is optimal for the questions posed and the specimens to be imaged.