Tailoring an Introductory Course in Biomedical Imaging*

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This paper presents choices of content for an introductory course in biomedical imaging. A sampling of presently offered introductory biomedical imaging courses demonstrated a considerable variety in available topic coverage. The principal topic areas include the technology of image formation and image processing methods. Examples of syllabi content are presented in the paper, together with a description of resources available for developing or upgrading biomedical imaging courses.

INTRODUCTION

THE DESIGN and delivery of imaging system technology is a significant segment of biomedical engineering activity. This significance is seen in the number of imaging courses offered at universities, in the announcement of job openings in biomedical imaging, and in the number of publications and articles in the engineering field devoted to biomedical imaging. This is an area of technology where new successes spur on yet further developments.

Introductory course work in biomedical imaging is of interest to the student who wants to become oriented to the field, who wants to gain topic exposure for the selection of a graduate program, and who may be seeking opportunities for applying creativity. The student learns about extending the visual 'reach' of the clinical healthcare provider and of the biomedical research investigator. This extension is accomplished by applying physical and mathematical principles in order to retrieve and process image information about the biological system. Specific to most of biomedical imaging is the requirement that the imaging be accomplished without significant biological invasion, or if the methods are invasive, that the risk and damage to the biological system are minimized. Typically, imaging requires extensive computation. The digital revolution in imaging, which became widespread in the mid-1960s has made possible many new imaging modalities, starting with the notable development of computer-aided tomography.

ENGINEERING TASKS IN BIOMEDICAL IMAGING COURSES

The clinical uses of images can be patient monitoring, diagnosis and therapy delivery. Research uses involve improving the understanding of the biological system. Realization of systems for these uses requires the carrying out of engineering designs and of engineering methods to create the successfully functioning imaging system.

Two categories of engineering tasks can be covered in the introductory imaging course. One category involves the selection of principles, design parameters, and features to optimize the performance of existing imaging systems. A related task in the same category is the creative development of new systems. Some of the students who take an introductory biomedical imaging course may go on to specialize in imaging and can be expected to develop new imaging modalities, not yet conceived. An example of a recent new imaging modality would be atomic force microscopy. The coverage in an introductory imaging course of existing imaging systems that have appeared and matured provides examples and inspiration to this group of students.

Another category is image processing and image analysis. Image production in which all technically obtainable features are acquired and retained is valued at a premium in many medical applications, in order that the clinicians have available maximum information about the biological system. The engineering role in image processing can also include preprocessing of raw image signals to remove noise and otherwise prepare signals for optimal image reconstruction. An entire area of significant importance revolves around the generation of quantitative insight, such as morphometry and change detection in biological images. One view of the image processing and analysis category is that it consists of a set of tools that are available for use in a broad range of applications.

The foregoing suggests two principal categories of course content; that is, image formation and image processing. The two categories are quite dissimilar. Image formation is primarily physics based, in which instrumentation and algorithms

build upon physical relationships. Image processing, on the other hand, is primarily heuristic based or model based, for the purpose of preparing the raw signals and images for their ultimate use. Both image formation and image processing have been viewed historically as essential components in the instrumentation education of the biomedical engineer (for example, M. P. Siedband, Medical Imaging Systems, Chapter 12, in *Medical Instrumentation,* ed. J. G. Webster). Arguments may be made for an emphasis on either image formation or on image processing in an introductory course.

The case for concentrating on image formation may rest on the highly significant value of imaging modalities in state-of-the-art diagnosis, monitoring and therapy. The technology of imaging systems currently in regular clinical use is relatively mature, given that the technology has reached the stage of medical use. However, substantial advances continue to be made in image performance and capability. For example, an improvement to magnetic resonance imaging consists of a way of tagging material points in the body via magnetic resonance spin tagging and then tracking the 3-D trajectory of these points. In another example, the imaging task may be to correct distortion due to projection of the approximately spherical shape of the retina into a planar image.

A case can also be made for inclusion of image processing/analysis in an introductory biomedical imaging course. The processing is specialized to both the image modality and to the application. As new modalities and applications continue to develop, the substantial demand for engineers to do image processing will continue. Noise and distortions inherent to the capture of image signals require processing of the raw signals. Additional processing can enhance images for optimal viewing and otherwise assist users in whatever applications are to be made of the images. For example, the task may be to select out features from cell images, or structures within the heart. Use of these methods by the engineer calls for an awareness of and proficiency in applying a broad range of known engineering tools for image processing that are heuristic-based and model-based. The engineer should also be able to create new tools when necessary.

PREREQUISITE IMAGING COURSES

Another decision to be made in selecting the content for an introductory imaging course is whether the course should be preceded by an introductory general imaging course without a biomedical emphasis. The case for the general imaging course is bolstered by recognizing that new directions for imaging are likely to cut across many other application areas in addition to biomedical applications. For example, further development of 3-D imaging systems, including

displays, will have many nonbiomedical uses as well as biomedical uses.

On the other hand, some imaging issues are specific to or specialized within biomedical applications. For example, the faithful match of images to features in the original biological system is particularly important in the medical arena since the features may be essential to monitoring, diagnosis and therapy. This requirement for faithfulness of match suggests that image quality is an important consideration in the imaging course. Another consideration is that the user—the clinician—remains an important component in the monitoring, diagnosis and therapy process. Since the clinician is a 'system' component, the psychophysics of vision becomes an important component in describing biomedical imaging. Finally, biomedical imaging is moving towards not just the morphology, but also imaging of biological dynamics and function. Examples would be the imaging of flows and metabolic parameters to characterize organ function. In such applications, the description of the biology generally can become more important to the understanding of the imaging system. Medical physics and/or biomathematics can also be included as prerequisites or corequisites when these courses are available and the pool of students taking the biomedical imaging course can be expected to have taken the prerequisite course material.

The decision as to prerequisite courses for an introductory imaging course does not have a single answer, and depends upon the environment in which the course is offered.

SYLLABUS TOPIC AREAS

Below are listed syllabus topic areas that may be included within the introductory biomedical imaging courses. The list is divided into topic areas with comments. The introductory content for the imaging course serves to supplement prerequisite requirements.

Introductory content
The introductory content for the imaging course serves to supplement prerequisite requirements. If the introductory course is not to exclude interested students, the prerequisites need to be at a minimum. If engineering students take the course as upper-level graduate students, the basic math and physics would be in place, including an exposure to linear systems.

- Deterministic and stochastic systems
- Estimation (least mean squares) and vectors
- Noise processes and aliasing
- Extension of methods from one to two and three dimensions
- Mathematical analysis
- Matrix theory, probability, computer programming
- Sampling theory, sampling, quantization.

Fundamentals of imaging physics

This topic area is shown as a separate category, but would likely be integrated with the imaging system descriptions that follow in the next topic area (Imaging System Principles, Components, Features, and Applications.) The reason for integrating the two categories is that the various imaging system modalities employ quite different physical principles and each modality will have special characteristics and requirements.

- Electromagnetic radiation and interactions with matter
- Optics, including lenses and reflection
- Generators, filters and detectors
- Biological effects of radiation
- Safety considerations.

Imaging system modalities—principles, components, features and applications

Each modality involves a substantial amount of specialized technology that is important to both understanding and engineering implementation. The decision as to how much information to include in an introductory course about each of these modalities is a difficult one. One approach is a brief survey of these modalities with emphasis on the creative aspect of new imaging modalities and features. If more coverage is desired then students could be asked to prepare an in-depth term paper related to one or more of these imaging modalities.

- Photon imaging
  — camera modeling, photographic film
  — confocal fluorescence microscopy
- X-ray imaging including tomographic methods
  — applications such as fluoroscopy, angiography, mammography
- Ultrasound imaging
- Radionuclide imaging
  — applications such as SPECT and PET
- Magnetic resonance imaging
- Other methods
  — thermographic
  — microwave imaging
  — holography
  — biomagnetic imaging (SQUID)
  — diffusion imaging.

Image formation/reconstruction

These algorithms are used by a variety of the imaging system modalities in the preceding topic area list, including both two-dimensional and three-dimensional methods. As in the preceding topic area, the topics are specialized to specific imaging modalities. An overview may be given, coupled with term papers or projects, to provide specialized in-depth coverage.

- Image transforms
- Tomography
- Projections, including filtered back projection
- Central slice theorem
- Fan beam
- MRI reconstruction.

Image characteristics and quality

This topic area is concerned with the imaging system performance. As previously noted, the quantitative description of image quality, and the topic of quality control, assume particular importance in the biomedical field, in order to enhance monitoring, diagnosis and therapy.

- Image degradation
- Spatial resolution
- Image signal and noise
- Image contrast
- Receiver operating characteristics
- Image artifacts

Image processing

This is a large topic area directed to the correction and enhancement of images. The topics can be expanded to cover assisting the user in feature or pattern recognition. For example, processing might assist the clinician in locating tumors in a lung image. One approach to topic area coverage is to introduce students to one of the image processing software applications package that contains prepackaged processing tools (e.g. *Adobe Photoshop, Scion Image*). The skills for software development in order to accomplish the various processing tasks may be left for a separate and more advanced course.

- Frequency space, inverse filtering; linear and nonlinear filtering, smoothing, sharpening, modification, transforming, Wiener
- Other transforms, Hough, color and space transforms
- Imaging geometry, translation, scaling, rotation, stereo
- Image registration and segmentation, edge detection, adaptive thresholding, arithmetic and logic operations (mask processing), binary images, skeletonizing, boundaries
- Image measurements, histograms

Other topic areas

The student can benefit from recognizing the tie-in to a variety of other engineering tools and other applications areas. These topics may not be directly associated with biomedical imaging but are important to the overall capability of the engineer. Also open for consideration are professional issues such as regulation and certification.

- Computer vision
- Feature recognition
- Image digitization and display (including 3-D images)
- Image representation, encoding, compression and restoration
- Optimizing processing speed

CHOICES OF COURSE CONTENT

The foregoing discussion suggests that choices must be made among alternatives in selecting

content for a biomedical imaging course, and the choices may not be clear-cut. In a quick survey of courses in biomedical imaging, the differences in orientation toward image formation and image processing were readily apparent. (See Acknowledgments below.) If these courses were mapped to a point along a line with image formation at one end and image processing at the other, then the quick survey suggests that introductory biomedical imaging courses appear to fall at many different points along the path. Then also, institutions may have complementary engineering courses and other imaging courses that cover the content not present in the sampled courses. At the author's institution, the coverage has been provided in separate courses for image generation and image processing.

RESOURCES

A variety of resources are available. A search of books available from one vendor (Amazon.com) showed 2757 different books on imaging and 469 books on medical imaging. A sampling of text titles as used in biomedical engineering imaging courses are given in the bibliography at the end of the paper. These texts are frequently supported with accompanying software and images. Many different journals provide state-of-the-art resource content on biomedical imaging including *IEEE Transactions on Image Processing, IEEE Transactions on Information Technology in Biomedicine, Journal of Biomedical Optics, Journal of Computer-Assisted Microscopy, Journal of the Optical Society of America, Analytical and Quantitative Cytometry and Histology,* and *Cytometry.*

One of the attractions to students in an imaging course is the ability to implement and test computational methods with real data. Use of the real medical images is a desirable motivational and experiential component of the course. A sampling of Internet image sites and sources for image processing packages are listed below (except for the last entry, from S. Blanchard at www.bae.ncsu.edu/bae/netinfo/taids.html, North Carolina State University)

- The Graphics, Visualization and Usability Center at Georgia Tech. (http://www.cc.gatech.edu/gvu/gvutop.html)
- Image Processing and Analysis Group, Departments of Diagnostic Radiology and Electrical Engineering, Yale School of Medicine. (http://noodle.med.yale.edu/)
- The Data Intensive Distributed Computing Research Group, and the Imaging and Distributed Collaboration Group, NERSC and Information and Computing Sciences Divisions, Ernest Orlando Lawrence Berkeley National Laboratory, One Cyclotron Road, 50B-2270, Berkeley, CA, USA 94720. (http://george.lbl.gov/)
- The Department of Radiology at Indiana University. (Radiology Images) (http://foyt.indyrad.iupui.edu/HomePage.html)
- The Medical College at Cornell University. (gopher://guru.med.cornell.edu/)
- Molecular Biology Server of the University of Geneva and The Geneva University Hospital. (http://expasy.hcuge.ch/sgifs/PEOPLE/hcuge2.gif)
- The University of Melbourne in Australia (gopher site). (gopher://gopher.austin.unimelb.edu.au/)
- The University of Washington Radiology Webserver. (http://www.rad.washington.edu/)
- The Virtual Hospital at the University of Iowa. (http://vh.radiology.uiowa.edu/)
- The National Library of Medicine Visible Human Project. (http://www.bae.ncsu.edu/bae/people/staff/caudill/rainbow_line.gif)
- Department of Radiology, Brigham and Women's Hospital, Harvard Medical School. (http://brighamrad.harvard.edu/)

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