ENGG4620 – ENGG6620
Biomedical Imaging

Syllabus Spring 2016 - M. Haidekker

1 Course Information

Fundamental principles and applications of noninvasive imaging modalities in medicine (X-rays, tomography, magnetic resonance, ultrasound); computer methods and algorithms for image processing, enhancement and analysis.

Offered: Every Fall semester
Credits: 3 credit hours
Class: Lectures on Tuesday and Thursday
Prerequisite: MATH2700 *Differential Equations*

Hardly any development in Medical Sciences has revolutionized medicine as much as the discovery that it was possible to look into the body without surgery. A hundred years ago, Conrad Wilhelm Röntgen discovered the X-rays. Since then, noninvasive imaging of the body literally got into new dimension with the invention of 3D tomography. CT and MRI allow to acquire cross-sectional images and to obtain three-dimensional reconstructions of structures. Two additional modalities will be covered, positron emission tomography (PET), which allows the imaging of tissue function. Particularly in conjunction with MRI, it allows new insights in the function of the brain. Ultrasound is a different modality. It is based on sound wave reflection, and its advantages are the relatively inexpensive equipment and the radiation-free principle.

These fascinating techniques are the topic of this class. We will look at the physical principles of X-rays and image formation with ionizing radiation. Moreover, we will cover the fundamentals of magnetic resonance and ultrasound imaging. The goal of this class is to understand physics and technology of those imaging modalities. The second half of the semester is dedicated to image processing and analysis. Most modern modalities rely heavily on computer processing of the measured data. Some image processing methods are inherent to the modality, such as the filtered backprojection in computed tomography or the Fourier transform of the k-space matrix in MRI. Of course, the computer can do more than provide the reconstructed images.

Spatial measurements (e.g. the size of an embryo in ultrasound) and density (e.g. bone mineral density in osteoporosis) can easily be performed. The computer can also aid in enhancing image quality, suppression of noise and other artifacts, or in segmenting an object of interest - the separation of that object from surrounding image regions. The class will cover the four important steps of image enhancement, segmentation, quantification, and visualization.

In short,

1. we will understand the concepts of image formation and image contrast, and the mechanisms that generate contrast from biological tissues.

2. we will learn the physical and mathematical foundations for modern tomographic imaging modalities, including CT, SPECT, PET, and MRI.

3. we will explore factors that influence image quality, and we will examine computerized methods that improve image quality

4. we will examine additional computerized image processing methods with the goal to separate objects from their background, and to extract quantitative metrics from images.

The philosophy of this course is to provide a broad background, even if some depth is sacrificed. The overall goal is to provide entry points for more specialized study. A special aspect of this course is the integration of image formation physics and computer methods. As such, the course touches on Computer Science aspects. Consistent with this philosophy are the homework assignments, which contain both theoretical aspects and actual hands-on components with image analysis software.

2 Instructor

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3 Syllabus – Topical Outline

Note: The course syllabus is a general plan for the course; deviations may be necessary and will be announced to the class by the instructor.

Lecture block	Topic
1	Introduction to Biomedical Imaging, its history and development
2	Imaging with ionizing radiation: Physics of x-ray imaging
3	Engineering aspects of x-ray imaging: X-ray generators and detectors
4	Brief introduction into the Fourier transform
5	Computed Tomography: Principles of image formation and reconstruction techniques
6	Computed Tomography: Engineering aspects of CT scanners
7	Nuclear imaging modalities: Scintigraphy, SPECT and PET
8	Magnetic Resonance Imaging: Physical foundations
9	Magnetic Resonance Imaging: Image formation
10	Ultrasound Imaging
11	Computerized image enhancement: Spatial-domain and Fourier-domain filters
12	Image segmentation (intensity-based)
13	Image segmentation, region-based and morphological approaches
14	Image quantification: Size, density, shape, texture
15	Outlook and trends in biomedical imaging

4 Class Materials

- Required: *Medical Imaging Technology* by Mark A. Haidekker, SpringerBriefs in Physics (Springer, 2013) [1]
- Chapters 2 and 3 of *Advanced Biomedical Image Analysis* by Mark A. Haidekker, John Wiley 2011, ISBN 978-0-470-62458-6 (available on-line through UGA library)
- Recommended additional reading: *Digital Image Processing for Medical Applications*, by Geoff Dougherty, Cambridge Press, ISBN 978-0-521-86085-7

A class web page exists at `http://photonics.engr.uga.edu/imaging`, and course details, homework assignments and announcements can be found on that web page.

[1] DISCLAIMER: Springer does not pay royalties to the author for the sale of this book, and no conflict of interest exists. Moreover, students can download the book free of charge through the UGA library.

Students are encouraged to visit that web page frequently.

5 Grading Policy

Grades will be assigned by a percentage of earned grade points. Grade points are awarded following the fill-the-bucket principle for:

- Homeworks (about 40% of the total score)
- Midterm exam (about 30% of the total score)
- Final exam (about 30% of the total score)

Grades are related to the percentage of earned grade points as follows:

Grade points (%)	Grade
95 or more	A
90 or more	A-
85 or more	B+
80 or more	B
75 or more	B-
70 or more	C+
65 or more	C
60 or more	C-
55 or more	D+
50 or more	D

The minimum passing score is 50% of the achievable score.

6 Reference to the University Honor Code and Academic Honesty Policy

As a University of Georgia student, you have agreed to abide by the Universitys academic honesty policy, A Culture of Honesty, and the Student Honor Code. All academic work must meet the standards described in A Culture of Honesty found at: `http://www.uga.edu/honesty`. Lack of knowledge of the academic honesty policy is not a reasonable explanation for a violation. Questions related to course assignments and the academic honesty policy should be directed to the instructor.

7 Course Learning Objectives

By the end of this course, students should:

1. understand the image formation process (physics and engineering aspects) of different imaging modalities

2. understand the mathematical foundations and the computer algorithms that are used in image formation and image reconstruction

3. appreciate current trends of medical imaging by being exposed to topical literature

4. be able to apply their knowledge on medical or nonmedical sample images in small lab-based projects

5. have designed a complete image analysis chain and implement it in a major experiment-based project

8 Additional ABET-Relevant Information

8.1 Student Outcomes

For Course Learning Objectives, see Section 7. Overall, this course contributes to the following Student Outcomes:

a. An ability to apply knowledge of mathematics, science, and engineering (yes)

b. An ability to design and conduct experiments, as well as to analyze and interpret data (yes)

c. An ability to design a system, component, or process to meet desired needs (yes)

d. An ability to function on multi-disciplinary teams (no)

e. An ability to identify, formulate, and solve engineering problems (yes)

f. An understanding of professional and ethical responsibility (no)

g. An ability to communicate effectively (yes)

h. The broad education necessary to understand the impact of engineering (no)

i. A recognition of the need for, and an ability to engage in life-long learning (yes)

j. A knowledge of contemporary issues (yes)

k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (yes)

The course learning objectives relate to the Student Learning Outcomes in detail as follows:

Course Learning Objective	Relationship to Student Outcome a	b	c	e	g	i	j	k
1. Understand the image formation process (physics and engineering aspects) of different imaging modalities	✓	–	–	✓	–	✓	✓	–
2. Understand mathematical foundations and computer algorithms used in image formation and reconstruction	✓	–	–	✓	–	–	✓	–
3. Appreciate current trends of medical imaging by being exposed to topical literature	–	–	–	–	–	✓	✓	–
4. Applied knowledge on medical or nonmedical sample images in small lab-based projects	✓	✓	✓	✓	–	–		✓
5. Design a complete image analysis chain and in a major experiment-based project	✓	✓	✓	✓	✓	–	–	✓

8.2 Assessment of Learning Objectives

1. Understand the image formation process: The knowledge and level of understanding is tested in Homeworks 1 and 3 and in the Midterm exam.

2. Understand the mathematical foundations and computer algorithms: The knowledge and level of understanding is tested in Homeworks 1 and 3 and in the Midterm exam.

3. Appreciate current trends of medical imaging by being exposed to topical literature: Topical literature is handed out as reading assignment. Formal assessment has yet to be developed.

4. Be able to apply their knowledge on sample images in small projects: The knowledge and level of understanding is tested in Homeworks 6 and 7 and in the Final exam.

5. Have designed a complete image analysis chain and implement it in a major experiment-based project: Homework 7 is a major design task without prescribed path to the goal. It requires a comprehensive, typewritten report.