# Advanced Topics in Biomedical Ultrasound Imaging
ECE 598PS
**Spring 2023**

**Instructor:** Pengfei Song, PhD (Assistant Professor)
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**Lecture:** 2:00-3:20PM Tuesdays and Thursdays, room ECEB 3017, 4 credit hours.

**Website**: https://courses.grainger.illinois.edu/ece598ps/sp2023/index.htm

**Pre-Requisites:** ECE 472 (Biomedical Ultrasound Imaging) or consent of instructor

**Course description:** this is a one-semester, 4-credit-hour course offered at the Grainger College of Engineering by the Department of Electrical and Computer Engineering. The overall objective of the course is to introduce students to the advanced and state-of-the-art topics and methods in the field of biomedical ultrasound imaging. At the beginning of the course, we will provide brief reviews of the fundamentals of biomedical ultrasound (covered in ECE 472). We will then move on to advanced topics including advanced beamforming, advanced imaging sequences, quantitative ultrasound, elastography, advanced blood flow imaging techniques, advanced 3D ultrasound imaging, and other advanced topics such as super-resolution imaging, molecular imaging and photoacoustic imaging. We will also introduce ultrasound simulation software including Field II and k-wave which will be used throughout the semester for homework assignments and final project.

**Student learning objectives:** upon completion of this course, the students will be able to describe the principles and state-of-the-art techniques for each advanced ultrasound imaging topic. The students are expected be able to use ultrasound simulation software to test and validate most of the advanced theories and imaging sequencies. Upon completion of the final project, the students will be able to identify, review, and critique literature, reproduce key results, and develop alternative or new solutions and theories that demonstrate better performance than the *status quo*.

**Office hour:** Location: Beckman 4041; Time: 4:00-5:00 PM, Tuesday and Thursday; other appointments available upon request.

**Course Grading:**
40% - homework;
20% - literature review and final project proposal;
40% - final project.

**Approximate Grade Scale:**

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|---|---|---|---|---|---|---|---|---|---|
| A+, | 95-100 | B+, | 87-89.9 | C+, | 77-79.9 | D+, | 67-69.9 | | |
| A, | 92-94.9 | B, | 83-86.9 | C, | 73-76.9 | D, | 63-66.9 | F, | 0-59.9 |
| A-, | 90-91.9 | B-, | 80-82.9 | C-, | 70-72.9 | D-, | 60-62.9 | | |

**Reference Material:** Lecture slides; select literature; recommended textbooks:
Foundations of Biomedical Ultrasound (by Richard S.C. Cobbold)
Diagnostic Ultrasound Imaging: Inside Out (2nd edition, by Thomas Szabo)
Fundamentals of Acoustics (4th edition, by Lawrence E. Kinsler et al.).
**Syllabus:** (topics covered- corresponding chapters in textbooks and other references)

Acoustic wave propagation – Cobbold 1.1-1.5; Kinsler 5.1-5.7
Attenuation in ultrasound – Cobbold 1.8
Intensity, impedance, reflection, transmission, scattering, diffraction – Cobbold 1.5-1.8
Ultrasonic Sources – Cobbold 6.1, 6.10
Fields – Cobbold 2.2-2.3, 3.1-3.8
Imaging arrays and beamforming – Cobbold 7.2.1-7.2.5, 7.3; Szabo 6, 7
Conventional ultrasound imaging modes – Cobbold 7.1
Doppler ultrasound – Cobbold 9.1-9.7, 10.1-10.5
Color flow imaging – Cobbold 10.7-10.8, 10.10
Advanced beamforming – Szabo 10.12; Cobbold 8.4-8.7; literature
Quantitative ultrasound – literature
Elastography – Szabo 16; Cobbold 8.8; literature
Advanced blood flow imaging techniques – Cobbold 10.10-10.12; Szabo 11.8-11.11; literature
Advanced 3D ultrasound imaging methods – Cobbold 7.3.2-7.3.3; Szabo 10.11.6; literature
Ultrasound simulation methods – literature
Molecular imaging and photoacoustic imaging – literature

**Class Schedule:**

| **Tuesday** | **Thursday** |
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| **Jan 17**<br>L1a: Review of the fundamentals (acoustic wave propagation, wave equations, wave interactions with tissue) | **Jan 19**<br>L1b: Review of the fundamentals (ultrasound source and field calculations) |
| **Jan 24**<br>L1c: Review of the fundamentals (ultrasound imaging arrays and basics of beamforming) | **Jan 26**<br>L1d: Review of the fundamentals (Conventional ultrasound imaging modes including A, B, C, M, Doppler, and color flow)<br>HW1 handout (fundamentals) |
| **Jan 31**<br>L2a: Ultrasound simulation methods (Field II) | **Feb 2**<br>L2b: Ultrasound simulation methods (k-wave)<br>HW1 due/HW2 handout (Field II and K-wave) |
| **Feb 7**<br>L3a: Beamforming: delay-and-sum (part I) | **Feb 9**<br>L3a: Beamforming: delay-and-sum (part II)<br>HW2 due/HW3 handout (DAS beamforming) |
| **Feb 14**<br>L3b: Beamforming: adaptive beamforming (part I) | **Feb 16**<br>L3b: Beamforming: adaptive beamforming (part II)<br>HW3 due |
| **Feb 21**<br>L3b: Beamforming: adaptive beamforming (part III)<br>HW4 handout (Adaptive beamforming) | **Feb 23**<br>L3c: Beamforming: phase aberration correction (part I) |
| **Feb 28**<br>L3c: Beamforming: phase aberration correction (part II) | **Mar 2**<br>L3c: Beamforming: phase aberration correction (part III)<br>HW4 due/HW5 handout (Phase aberration correction) |
| **Mar 7** | **Mar 9** |

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|---|---|
| L4a: Imaging sequences: synthetic aperture imaging | L4b: Imaging sequences: compounding plane wave imaging (part I)<br>HW5 due |
| **Spring break no class (Mar 14, 16)** | |
| **Mar 21**<br>L4b: Imaging sequences: compounding plane wave imaging (part II)<br>HW6 handout (synthetic aperture and compounding plane wave simulation) | **Mar 23**<br>L4c: Imaging sequences: coded excitation (part I) |
| **Mar 28 (AIUM)**<br>L4c: Imaging sequences: coded excitation (part II)<br>HW6 due/HW7 handout (coded excitation) | **Mar 30**<br>L4d: Imaging sequences: nonlinear imaging (part I) |
| **Apr 4**<br>L4d: Imaging sequences: nonlinear imaging (part II)<br>HW7 due/HW8 handout (nonlinear imaging) | **Apr 6**<br>L5a: Elastography (basics of ultrasound motion detection) |
| **Apr 11**<br>L5b: Elastography (strain and shear wave elastography)<br>HW8 due/HW9 handout (elastography) | **Apr 13**<br>L6a: Advanced blood flow imaging techniques (review of Doppler) |
| **Apr 18**<br>L6b: Advanced blood flow imaging techniques (ultrafast Doppler, functional ultrasound)<br>HW9 due/HW10 handout (advanced Doppler) | **Apr 20**<br>L6c: Advanced blood flow imaging techniques (super-resolution microvascular imaging) |
| **Apr 25**<br>L7: Quantitative ultrasound and ultrasound tomography (Invited speaker: Prof. Michael Oelze)<br>HW10 due<br>Paper selection deadline | **Apr 27**<br>L8: Other advanced topics (3D imaging, molecular imaging, photoacoustic imaging). |
| **May 2**<br>Final project proposal presentation | **May 4**<br>Reading day |
| **May 10**<br>Final project presentation | |

**Homework:**
There will be 10 graded homework sets for this course. Homework assignments will be distributed on-line and will be graded with Gradescope. Solutions will be posted on the course website. Late homework will **NOT** be accepted. Detailed homework assignment schedule and deadline are given in the class schedule.

Please register on Gradescope using your real name and your Illinois email account with your netID. The site is FERPA compliant. The entry code to the course on Gradescope is TBD.

**Final project:**
The final project serves as the final exam of the class. There are two stages for the final project. In the first stage, each student is asked to pick and review at least one peer-reviewed journal article that is related to at least one of the topics discussed in class. The student then gives an in-class presentation to

provide an introduction of the selected article(s) (e.g., in a journal club style), based on which the student proposes a final project. A Q&A will be conducted along with the presentations. The students are encouraged to select papers and projects that match their research interests. Projects that allow the students to use their research data (e.g., simulation, phantom experiment) are highly encouraged. A final project presentation (with Q&A) will be conducted on the final exam day. Grades associated with the final project will be given based on the quality of the literature review, the proposal, the final project presentation.

Grading rubrics of the final project:

- Proposal presentation:
  - Problem statement and literature review
  - Depth of understanding of the methodology
  - Critiques for the reviewed paper
  - Plans for the proposed project
  - Potential challenges/pitfalls and alternative solutions
  - Quality of the presentation
- Final project presentation:
  - Level of execution and completeness of the proposed project
  - Quality of data analysis (both qualitative and quantitative)
  - Quality of the discussion
  - Quality of the presentation

**Software:**
For this course, we will use MATLAB for completing problems in the homework sets and final projects. If you have never used MATLAB, please contact me for introductory material on how to acquire and use MATLAB.

**Grade Disputes:**
All grade disputes associated with homework assignments should be submitted (through Gradescope) within one week from the returning of your graded homework.

**Other statements:**

**Sexual Misconduct Reporting Obligation**
The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: wecare.illinois.edu.

**Academic Integrity**
The University of Illinois at Urbana-Champaign Student Code should also be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/.

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not

an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor(s) if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

**Religious Observances**
Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. You should examine this syllabus at the beginning of the semester for potential conflicts between course deadlines and any of your religious observances. If a conflict exists, you should notify your instructor of the conflict and follow the procedure at https://odos.illinois.edu/community-of-care/resources/students/religious-observances/ to request appropriate accommodations. This should be done in the first two weeks of classes.

**Disability-Related Accommodations**
To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability. You may access these by visiting the DRES website and selecting "Request an Academic Screening" at the bottom of the page.

**Family Educational Rights and Privacy Act (FERPA)**
Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

**Anti-Racism and Inclusivity**
The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

**Counseling and help:**
If you need mental health counseling or help, don't hesitate to contact the Counseling Center (https://www.counselingcenter.illinois.edu) which provides services to address emotional,

interpersonal, and academic concerns. The Center also provides emergency service (https://www.counselingcenter.illinois.edu/emergency-0). Another option that you have is to contact the ECE department advising office (Jen Merry, merry@illinois.edu, 217-333-9710), or the advising office in your perspective department if you are not an ECE student. Of course you can always contact me if you have any concerns or need any help.