COURSE DESCRIPTION: Fundamental physics and instrumentation of biomedical ultrasound imaging presented at a level suited to graduate students performing thesis research in ultrasound imaging. The course will encourage students to develop a unified conceptual and mathematical understanding of ultrasound imaging and will emphasize the use of computer simulation to illustrate and extend key concepts. Topics covered will include physical acoustics, beam and image formation, coherent speckle, and blood-flow and tissue-motion estimation. Course cross-listed as: Biomed 9640, Biophysics 9640, ECE 9204, and Physics 9640.

COURSE INSTRUCTORS:
• T. L. Poepping, PhD  
  Course coordinator  
  Physics & Astronomy Building, PAB 236  
  E-mail: poepping@uwo.ca
  
• J. C. Lacefield, PhD, PEng.  
  Thompson Engineering Building, TEB 371  
  and Robarts Research Institute RRI 1254B  
  E-mail: jlacefie@uwo.ca

CONTACT HOURS: 3 lecture hours per week (Mon 1-2:30, Fri 9:30-11; PAB49, starting Jan 13).

PRE-REQUISITES: Biomedical Engineering 9513 or BIOPHYS 9515 or MEDBIO 4475 or permission from the instructors.

ANTI-REQUISITES: Course is cross-listed as: Biomed 9640, Biophysics 9640, ECE 9204, and Physics 9640; therefore a student may only receive credit for one of these courses.

TOPICS:
1. Linear ultrasonic wave propagation, reflection, transmission, attenuation, and scattering;
2. Ultrasound system architecture, beam formation, and image formation;
3. Statistical models of image speckle with applications to lesion detection and tissue characterization;
4. Doppler and correlation-based methods of blood-flow and tissue-motion estimation;
5. Ultrasound simulation software.

SPECIFIC LEARNING OBJECTIVES:
Students will be able to…
1. Produce physically consistent conceptual and mathematical descriptions of propagation, reflection, absorption, scattering, and diffraction of ultrasonic plane waves, and relate those descriptions to the practical characteristics of ultrasound images and imaging systems.
2. Specify and implement in software the principal signal processing and image display operations performed during ultrasound anatomical and blood-flow imaging.
3. Estimate and numerically demonstrate the effects of array and system design parameters on the three-dimensional point-spread function of an ultrasound imaging system.
4. Apply statistical and computational models of ultrasound speckle to analyze the performance of commonly employed image analysis and image enhancement techniques.
5. Formulate evidence-based assessments of the current effectiveness and future potential of ultrasound for specific diagnostic imaging applications.

COURSE MATERIALS:

The Shung textbook is available electronically through Western Libraries. The other resources below have been put on short-loan reserve at Western's Taylor Library (1-DAY loan). Additional readings will be accessible electronically using Western Libraries (via links in OWL).

Other general resources for supplemental reading:

EVALUATION:
The final course mark will be based on the student's performance in homework assignments, oral presentation, and peer evaluation of oral presentations. Four or five homework assignments, consisting of both analytical and computer simulation problems, will be required. Each student will present one 20-minute lecture on a topic relevant to the course material that will be chosen in consultation with the instructors. Students (including those auditing the course) will be required to attend their classmates' lectures and complete written peer evaluations.

To obtain a passing grade in the course, a student must achieve a minimum mark of 50% on the oral presentation and participation components, with an overall weighted average of at least 50%. An oral presentation or participation mark below 50% will result in a course mark of 48% or less.

The course mark will be computed using the weights listed in the following table:

<table>
<thead>
<tr>
<th>Component</th>
<th>Duration</th>
<th>Weight</th>
<th>English</th>
<th>Presentation</th>
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</thead>
<tbody>
<tr>
<td>Assignments</td>
<td></td>
<td>70%</td>
<td>5%</td>
<td>5%</td>
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<tr>
<td>Oral Presentations</td>
<td>20 min</td>
<td>20%</td>
<td>5%</td>
<td>5%</td>
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<tr>
<td>Participation (peer eval.)</td>
<td></td>
<td>10%</td>
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*In accordance with the policy of the University, the grade assigned to all written and oral work presented in English shall take into account syntax, diction, grammar and spelling. In the professional life of an engineer or scientist, the manner in which oral and written communications are presented is extremely important. A student must develop these skills as an integral part of their education. To encourage the student to do so, the grades assigned to all written and oral work will take into account all aspects of presentation including conciseness, organization,
neatness, use of headings, and the preparation and use of tables and figures. All work will be marked first for content, after which a maximum penalty of 5% each may be applied for lack of proficiency in English and/or presentation.

**LECTURES OUTLINE:**

0. Clinical applications; advantages, disadvantages, and misconceptions; industry snapshot

1. Basic principles of acoustic wave propagation
   a. Acoustic wave equation
   b. Intensity (including dB scale)
   c. Acoustic properties: density, compressibility, sound speed, impedance
   d. Reflection, refraction, transmission (including layered media)
   e. Attenuation, absorption, scattering
   f. Nonlinearity and radiation force
   g. Biological effects of ultrasound
   h. Diffraction, near field, far field, beam spread (Fresnel and Fraunhofer integrals)

2. Basic ultrasound imaging
   a. A-line, B-mode, M-mode
   b. Attenuation (time-gain) compensation, envelope detection, logarithmic compression, scan conversion
   c. Resolution, frame rate, field of view

3. Ultrasonic systems, transducers and arrays
   a. Piezoelectric effect, transmitters, receivers (simple transducer models, e.g., to predict pulse characteristics)
   b. Beamforming, side-lobe and grating-lobe suppression
   c. Linear, phased, multi-row, and 2-D arrays
   d. Point-spread function computations using Field II

4. Statistical models of image speckle
   a. Random walk model, Rayleigh PDF, effects of log compression
   b. Second-order speckle statistics
   c. Lesion detectability and speckle reduction
   d. Non-Rayleigh speckle and tissue characterization
   e. Simulation of speckle images using Field II

5. Ultrasound motion (blood-flow and tissue-motion) imaging
   a. Spectral Doppler
      i. Doppler effect and Doppler equation, spectral display
      ii. CW processing: quadrature demodulation and directional Doppler
      iii. PW processing: pulse ensembles, slow time and fast time, velocity aliasing and range limitation
      iv. Wall filters
      v. Clinical applications
   b. Color Flow Imaging
      i. Color, power, and tissue Doppler images
      ii. Kasai autocorrelation (phase-shift) velocity estimator
      iii. Speckle tracking (time-shift) velocity estimators
      iv. Vascular quantification and clinical applications
      v. Tissue Doppler
      vi. Simulation of color flow images using Field II
   c. Elasticity imaging
ADMINISTRATIVE POLICIES:
Please refer to the UWO Academic Policies http://www.uwo.ca/univsec/academic_policies/ for further details on the policies in practice here.

1. Accommodations: The only acceptable excuses for missing an examination are serious personal illness, immediate-family bereavement, or approved religious conflicts.

Absences & Illness—If you are unable to meet a course requirement due to illness or other serious circumstances, you must provide valid medical or other supporting documentation to the Dean's office as soon as possible and contact your instructor immediately. It is the student's responsibility to make alternative arrangements with their instructor once the accommodation has been approved and the instructor has been informed. In the event of a missed final exam, a "Recommendation of Special Examination" form must be obtained from the Dean's Office immediately. For further information please see: http://www.uwo.ca/univsec/pdf/academic_policies/appeals/medical.pdf.

A student requiring academic accommodation due to illness should use the Student Medical Certificate when visiting an off-campus medical facility or request a Record's Release Form (located in the Dean's Office) for visits to Student Health Services. The form can be found here: https://studentservices.uwo.ca/secure/medical_document.pdf. Students who are in emotional or mental distress should refer to Mental Health@Western http://www.uwo.ca/uwocom/mentalhealth/ for a complete list of options about how to obtain help.

Accommodations for Religious Holidays—When scheduling unavoidably conflicts with religious holidays which a) require an absence from the University or b) prohibit or require certain activities (i.e., activities that would make it impossible for the student to satisfy the academic requirements scheduled on the day(s) involved), no student will be penalized for absence because of religious reasons, and alternative means will be sought for satisfying the academic requirements involved. If a suitable arrangement cannot be worked out between the student and instructor involved, they should consult the appropriate department chair and, if necessary, the student's Dean.

It is the responsibility of such students to inform themselves concerning the work done in classes from which they are absent and to take appropriate action.

A student who, for either of the situations outlined in paragraph one above (a or b), is unable to write examinations and term tests on a Sabbath or Holy Day in a particular term shall give notice of this fact in writing to his or her Dean as early as possible, but not later than November 15 for mid-year examinations and March 1 for final examinations, i.e., approximately two weeks after the posting of the mid-year and final examination schedule respectively. In the case of mid-term tests, such notification is to be given in writing to the instructor within 48 hours of the announcement of the date of the mid-term test. If a Special Examination is offered as an alternative means to satisfy the academic requirements, the instructor(s) in the case of mid-term tests and the dean in the case of mid-year and Spring final examinations will arrange for special examination(s) to be written at another time. In the case of mid-year and Spring final examinations, the accommodation must occur no later than one month after the end of the examination period involved. It is mandatory that students seeking accommodations under this policy give notification before the deadlines and that the Faculty accommodate these requests.

For purposes of this policy the University has approved a list of dates which are recognized religious holidays which require members of those religions to be absent from the University; this list is updated annually and is available at Departmental, Deans' and Faculty advising offices.
Accessibility—Please contact the course instructor if you require material in an alternate format or if any other arrangements can make this course more accessible to you. You may also wish to contact Services for Students with Disabilities (SSD) at 661-2111 x 82147 for any specific question regarding an accommodation.

2. Make-up Policy for Final Examinations: In accordance with Senate Policy, a Special Examination will be held within thirty days of the regular final examination for students who are unable to write the regular examination for medical or other documented reasons. Requests for such a Special Examination must be made to the Associate Dean, Faculty of Science. Note that if you fail to write a scheduled Special Examination, permission to write another Special Examination will be granted only with the permission of the Dean in exceptional circumstances and with appropriate supporting documents. In such a case, the date of this Special Examination normally will be the scheduled date for the final exam the next time the course is offered.

3. Cheating and Plagiarism: University Policy states that cheating, including plagiarism, is a major scholastic offence. The commission of a scholastic offence is attended by academic penalties that might include expulsion from the program. If you are caught cheating, there will be no second warning.

As per the UWO Academic Policies, “Plagiarism: Students must write their essays and assignments in their own words. Whenever students take an idea, or a passage from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing, such as footnotes or citations.” All required papers may be subject to submission for textual similarity review to the commercial plagiarism-detection software under license to the University for the detection of plagiarism. All papers submitted for such checking will be included as source documents in the reference database for the purpose of detecting plagiarism of papers subsequently submitted to the system. Use of the service is subject to the licensing agreement, currently between The University of Western Ontario and Turnitin.com (http://www.turnitin.com).”