

Biomedical Imaging and Instrumentation Focus Area -
 Upper-Level Engineering Courses – updated June, 2019
 For BME Class of 2021 and beyond

EN.510.311	Structure of Materials	3
EN.510.313	Mechanical Properties of Materials	3
EN.510.314	Electronic Properties of Materials	3
EN.510.316	Biomaterials I	3
EN.510.403	Materials Characterization	3
EN.510.407	Biomaterials II: Host response and biomaterials applications	3
EN.510.422	Micro and Nano Structured Materials & Devices	3
EN.510.430	Biomaterials Lab	3
EN.520.315	Introduction to Bio-Inspired Processing of Audio-Visual Signals	3
EN.520.340	Introduction to Mechatronics	3
EN.520.349	Microprocessor Lab I	3
EN.520.353	Control Systems	3
EN.520.372	Programmable Device Lab	3
EN.520.385	Signals, Systems and Machine Learning	3
EN.520.414	Image Processing & Analysis	3
EN.520.415	Image Process & Analysis II	3
EN.520.417	Computation for Engineers	3
EN.520.424	FPGA Synthesis Lab	3
EN.520.427	Design of Biomedical Instruments and Systems	3
EN.520.432	Medical Imaging Systems	3
EN.520.433	Medical Image Analysis	3
EN.520.435	Digital Signal Processing	3
EN.520.447	Information Theory	3
EN.520.448	Electronics Design Laboratory	3
EN.520.450	Advanced Microprocessor Lab	3
EN.520.453	Advanced ECE Engineering Team Project	3
EN.520.454	Control Systems Design	3
EN.520.483	Bio-Photonics Laboratory	3
EN.520.491	CAD Design of Digital VLSI Systems I	3
EN.520.492	Mixed-Mode VLSI Systems	3
EN.520.495	Microfabrication Laboratory	4
EN.520.631	Ultrasound and Photoacoustic Beamforming	3
EN.520.646	Wavelets & Filter Banks	3
EN.520.651	Random Signal Analysis	3
EN.520.673	Magnetic Resonance in Medicine	3
EN.520.746	Seminar: Medical Image Analysis	3
EN.530.381	Engineering Design Process	3
EN.530.414	Computer-Aided Design	3
EN.530.420	Robot Sensors and Actuators	3
EN.530.421	Mechatronics	3

EN.530.441	Introduction to Biophotonics	3
EN.530.446	Experimental Methods in Biomechanics	3
EN.530.473	Molecular Spectroscopy and Imaging	3
EN.530.474	Effective and Economic Design for Biomedical Instrumentation	3
EN.530.646	Robot Devices, Kinematics, Dynamics, and Control	3
EN.530.672	Biosensing & BioMEMS	3
EN.530.691	Haptic Interface Design for Human-Robot Interaction	3
EN.540.403	Colloids and Nanoparticles	3
EN.540.440	Micro/Nanotechnology: The Science and Eng of Small Structures	3
EN.553.361	Introduction to Optimization	4
EN.553.362	Optimization II	4
EN.553.391	Dynamical Systems	4
EN.553.413	Applied Statistics and Data Analysis	4
EN.553.420	Introduction to Probability	4
EN.553.426	Introduction to Stochastic Processes	4
EN.553.430	Introduction to Statistics	4
EN.553.433	Monte Carlo Methods	3
EN.553.436	Data Mining	4
EN.553.472	Graph Theory	4
EN.553.493	Mathematical Image Analysis	3
EN.553.630	Statistical Theory	4
EN.553.761	Nonlinear Optimization I	3
EN.553.762	Nonlinear Optimization II	3
EN.580.435	Applied Bioelectrical Engineering I	1.5
EN.580.436	Applied Bioelectrical Engineering II	1.5
EN.580.456	Introduction to Rehabilitation Engineering	3
EN.580.457	Rehabilitation Engineering Design Lab	3
EN.580.471	Principles of Design of BME Instrumentation	4
EN.580.479	X-ray Imaging and Computed Tomography	3
EN.580.491	Learning Theory	3
EN.580.493	Imaging Instrumentation	3
EN.580.494	Build an Imager	3
EN.580.571	Honors Instrumentation	2
EN.580.678	Biomedical Photonics	3
EN.580.740	Surgery for Engineers	3
EN.601.315	Databases	3
EN.601.454	Augmented Reality	3
EN.601.455	Computer Integrated Surgery I	4
EN.601.456	Computer Integrated Surgery II	3
EN.601.461	Computer Vision	3
EN.601.463	Algorithms for Sensor Based Robotics	
EN.601.475	Introduction to Machine Learning	3
EN.601.482	Machine Learning: Deep Learning	3

Contact the department advising office for course additions.

200-Level Engineering Courses

(maximum of 3 credits from this list may count in focus area)

EN.520.214	Signals and Systems I	4
EN.520.230	Mastering Electronics	3
EN.530.241	Electronics and Instrumentation	3

Non Upper-Level Focus Area Courses

(maximum of 3 credits from this list may count in focus area)

AS.110.405	Introduction to Real Analysis	4
AS.110.443	Fourier Analysis	4
EN.580.112	BME Design Group	3
EN.580.211	BME Design Group	3
EN.580.212	BME Design Group	3
EN.580.311	BME Design Group	3
EN.580.312	BME Design Group	3
EN.580.411	BME Design Group	3
EN.580.412	BME Design Group	3
EN.580.580	Senior Design Project	3
EN.580.581	Senior Design Project	3

Students may use a maximum of 3 research credits as a non-upper-level engineering course.

Imaging and Instrumentation Sub-Areas

Imaging Instrumentation		
EN.520.432	Medical Imaging Systems	3
EN.580.493	Imaging Instrumentation	3
EN.580.479	X-ray Imaging and Computed Tomography	3
EN.520.673	Magnetic Resonance in Medicine	3
EN.580.678	Biomedical Photonics	3
EN.520.631	Ultrasound and Photoacoustic Beamforming	3
EN.530.441	Introduction to Biophotonics	3
EN.520.483	Bio-Photonics Laboratory	3
Biomedical Instrumentation and Electronics		
EN.580.471	Principles of Design of BME Instrumentation	4
EN.580.571	Honors Instrumentation	2
EN.520.315	Introduction to Bio-Inspired Processing of Audio-Visual Signals	3
EN.580.435	Applied Bioelectrical Engineering I	1.5
EN.580.436	Applied Bioelectrical Engineering II	1.5
EN.520.349	Microprocessor Lab I	3
EN.520.372	Programmable Device Lab	3
EN.520.448	Electronics Design Lab	3
EN.520.450	Advanced Micro-Processor Lab	3
EN.520.491	CAD Design of Digital VLSI Systems I	3
EN.520.492	Mixed-Mode VLSI Systems	3
EN.520.424	FPGA Synthesis Lab	3
Surgical Systems and Robotics		
EN.520.353	Control Systems	3

EN.520.454	Control Systems Design	3
EN.530.421	Mechatronics	3
EN.530.414	Computer-Aided Design	3
EN.530.420	Robot Sensors/Actuators	4
EN.530.646	Robot Devices, Kinematics, Dynamics, and Control	3
EN.601.463	Algorithms for Sensor Based Robotics	3
EN.580.456	Introduction to Rehabilitation Engineering	3
EN.580.457	Rehabilitation Engineering Design Lab	3
EN.530.446	Experimental Methods in Biomechanics	3
EN.600.484	Augmented Reality	3
EN.601.655	Computer Integrated Surgery I	4
EN.600.646	Computer Integrated Surgery II	3
EN.580.740	Surgery for Engineers	3
Micro-nanotechnology		
EN.540.440	Micro/Nanotechnology: The Science and Eng. of Small Structures	3
EN.530.672	Biosensing & BioMEMS	3
EN.580.495	Microfabrication Lab	4
EN.540.403	Colloids and Nanoparticles	3
EN.510.422	Micro and Nano Structured Materials & Devices	3
EN.510.311	Structure of Materials	3
EN.510.313	Mechanical Properties of Materials	3
EN.510.314	Electronic Properties of Materials	3
EN.510.316	Biomaterials I	3
EN.510.407	Biomaterials II: Host response and biomaterials applications	3
EN.510.430	Biomaterials Lab	3
EN.510.403	Materials Characterization	3
Data Analysis and Processing		
EN.520.414	Image Processing & Analysis	3
EN.520.415	Image Processing & Analysis II	3
EN.520.746	Seminar: Medical Image Analysis	3
EN.520.433	Medical Image Analysis	3
EN.553.493	Mathematical Image Analysis	3
EN.601.461/661/761	Computer Vision	3
EN.520.435	Digital Signal Processing	3
EN.520.447	Information Theory	3
EN.520.646	Wavelets & Filter Banks	3
EN.520.651	Random Signal Analysis	3
EN.553.661	Foundations of Optimization (Optimization in Finance)	4
EN.553.361	Introduction to Optimization	4
EN.553.362	Introduction to Optimization II	4
EN.553.762	Nonlinear Optimization	3
EN.553.391	Dynamical Systems	4
EN.553.472	Graph Theory	4
EN.553.420	Introduction to Probability	4
EN.553.426	Introduction to Stochastic Processes	4
EN.553.430	Introduction to Statistics	4

EN.553.620	Probability Theory I	4
EN.553.630	Statistical Theory (Introduction to Statistics)	4
EN.553.433	Monte Carlo Methods	3
EN.553.413	Applied Statistics and Data Analysis	4
EN.553.436	Data Mining	4
EN.601.226	Data Structures	4
EN.601.315	Databases	3
EN.580.491	Learning Theory	3
EN.601.475	Introduction to Machine Learning	3
EN.601.482	Machine Learning: Deep Learning	3

Imaging and Instrumentation

ULE Course Categories

COURSE CATEGORIES

Courses within the Imaging and Instrumentation Focus Area are broadly categorized as: **IMAGING INSTRUMENTATION, BIOMEDICAL INSTRUMENTATION AND ELECTRONICS, SURGICAL SYSTEMS AND ROBOTICS, DATA ANALYSIS AND PROCESSING, MICRO-NANOTECHNOLOGY.**

The **IMAGING INSTRUMENTATION** category includes courses concerning imaging devices and systems for applications in evaluation of biological samples, preclinical studies, and diagnosis and/or treatment of disease.

The **BIOMEDICAL INSTRUMENTATION AND ELECTRONICS** category includes courses concerning biomedical devices and sensors, in particular for capturing 1-dimensional bio-signals, combined with coursework providing relevant background in electronics.

The **SURGICAL SYSTEMS AND ROBOTICS** category includes courses concerning systems for surgical guidance and decision support, robotic-assisted surgery, as well as general biomedical applications of robotics.

The **MICRO-NANOTECHNOLOGY** category is focused on courses on miniaturized biosensors and devices, micro/nano materials, and microfabrication.

The **DATA ANALYSIS AND PROCESSING** category concerns mathematical and information-theoretic aspects of signal and data analysis, focusing on methods relevant to data generated by biomedical imaging systems and other biomedical instrumentation.

CORE COURSES

Students in the Imaging and Instrumentation Focus Area must take three required courses, each course representing a different category from the table below:

Category	Course Number	Title
Imaging Instrumentation	580.472	Medical Imaging Systems
	or 580.493	Imaging Instrumentation
	or 530.441	Introduction to Biophotonics
	or 520.483	Bio-Photonics Laboratory
Biomedical Instrumentation and Electronics	580.471	Principles of Design of BME Instrumentation
	or 520.372	Programmable Device Lab
	or 520.448	Electronics Design Lab
	or 580.435 + 436	Applied Bioelectrical Engineering I + II
Surgical Systems and Robotics	601.655	Computer Integrated Surgery I
	or 530.646	Robot Devices, Kinematics, Dynamics, and Control
	or 530.420	Robot Sensors/Actuators
	or 530.421	Mechatronics
Micro-nanotechnology	540.440	Micro/Nanotechnology: The Science and Eng. of Small Structures
	or 510.422	Micro and Nano Structured Materials & Devices
	or 530.672	Biosensing & BioMEMS
	or 510.316	Biomaterials I
Data Analysis and Processing	520.433	Medical Image Analysis
	or 520.435	Digital Signal Processing
	or 520.414	Image Processing and Analysis I
	or 601.461/661/761	Computer Vision

ADDITIONAL CATEGORY COURSES

In addition to the three required courses above, undergraduate students are encouraged to select additional Imaging and Instrumentation courses among their electives in the 3rd and 4th year. Ideally, this should amount to two or three courses spanning more than one of the categories listed above. (see the ULE table at the beginning of this document).

Imaging

ULE Course Categories

COURSE CATEGORIES

Courses within the Imaging Focus Area are broadly categorized as: **MEDICAL IMAGING**, **BIOLOGICAL IMAGING**, and **IMAGE ANALYSIS**.

CORE COURSES

Students in the Imaging Focus Area must take at least one course from each of the following categories – a total of three required courses: one from Medical Imaging, one from Biological Imaging, and one from Image Analysis.

Category	Course Number	Title
Medical Imaging	580.472	Medical Imaging Systems
	or 580.473	Modern Biomedical Imaging, Instrumentation, and Techniques
Biological Imaging	580.474	Molecular and Cellular Imaging
	or 580.478	Biomedical Photonics
	or 020.395	Fundamentals of Biological Light Microscopy
	or 020.397	Fundamentals of Biological Electron Microscopy
	or ME110.807	Fundamentals of Fluorescence and Confocal Microscopy
or MD110.808	Essentials of Electron Microscopy	
Image Analysis	580.322	Introduction to Medical Image Analysis
	or 580.466	Statistical Methods in Imaging
	or 520.414	Image Processing and Analysis I
	or 520.433	Medical Image Analysis
	or 600.361	Computer Vision
For Graduate Students	520.214	Signals and Systems

ADDITIONAL CATEGORY COURSES

In addition to the three required courses above, undergraduate students are encouraged to select additional courses from each category among their electives in the 3rd and 4th year – for example, one or two from each category. Graduate students should sample similarly from each category and focus more deeply within the category most relevant to their area of interest / research.

The **MEDICAL IMAGING** category includes courses concerning medical imaging (of humans) for purposes of diagnosis and/or treatment of disease.

Course Number	Title
520.673	Magnetic Resonance in Medicine
520.748	Seminar on Magnetic Resonance in Medicine
580.476 / 673	Magnetic Resonance in Medicine
580.479 / 679	X-ray Imaging and Computed Tomography
580.483 / 683	Nuclear Medicine
580.484 / 694	Ultrasound Imaging
580.493 / 693	Imaging Instrumentation
580.748	Seminar on Magnetic Resonance in Medicine
600.445	Computer-Integrated Surgery I
600.446	Computer-Integrated Surgery II

The **BIOLOGICAL IMAGING** category includes courses concerning imaging in biological applications – for example, microscopy and a variety of preclinical imaging methods for understanding fundamental cellular, molecular, and physiological mechanisms related to the biological basis of disease.

Course Number	Title
520.326	Introduction to Optical Instrumentation
520.413	Introduction to Photonics
520.483	Bio-Photonics Laboratory
580.470	Biomedical Instrumentation I: Molecular and Cellular
580.474	Molecular and Cellular Imaging
580.485 / 685	Topics in Advanced Microscopy

The **IMAGE ANALYSIS** category includes courses concerning mathematical, analytical, and information-theoretic aspects of biomedical imaging – typically irrespective of a given imaging modality or application.

Course Number	Title
520.414	Image Processing and Analysis I
520.415	Image Processing and Analysis II
520.433	Medical Image Analysis
520.447	Intro to Information Theory and Coding
520.746	Medical Image Analysis Seminar

550.437	Information, Statistics, and Perception
550.493	Mathematical Image Analysis
580.466	Statistical Methods in Imaging
580.681	Advanced Topics in Computer Vision
580.692	Advanced Topics in Machine Learning
600.361	Computer Vision
600.461	Computer Vision
600.475	Machine Learning
600.746	Medical Image Analysis Seminar

Example Undergraduate Course Trajectory

Focus Area credit requirements are as follows:

- 21 credits, with at least 18 credits from upper level engineering (ULE)
- Up to 3 credits can be used for:
 - Approved non-ULE courses (from the focus area list)
 - Focus area-related research
 - Design Team
 - 580.580/581
- “Specialty” focus area (combination of 2 focus areas) can be petitioned with Cathy and Dr. Tung. Rules are in the BME Undergraduate Advising Manual.

Example Trajectory: IMAGING FOCUS AREA (NO AP CREDITS)

