Core courses

Faculty of Science and Engineering

Molecular Imaging and Engineering

Full course description

The development of light microscopy by Antoni van Leeuwenhoek in the 17th century resulted in many scientific discoveries and the establishment of microbiology as a scientific discipline. The development of new imaging technologies and associated fundamental discoveries can similarly lead to groundbreaking progress and new disciplines. This course sets the stage for a new type of professional who understands and addresses contemporary challenges in the field of molecular imaging and engineering. Individual imaging techniques as well as the combination and integration of several imaging techniques, called multimodal imaging, provide large amounts of anatomical, functional and molecular information.

In this course, you are provided with the basic knowledge and tools required to cross the boundaries between scientific and engineering disciplines. You familiarise yourself with fundamental principles of physics, (bio)chemistry and engineering to establish a common theoretical base among students from different educational backgrounds. These fundamental principles underlying the various disciplines within the programme are further explored in lectures, tutorials and skills training sessions within the context of real-life examples and with the involvement of different imaging experts. In addition, students familiarize themselves with the conventions and expectations of the interdisciplinary field of molecular imaging and engineering, the specializations as well as the professional field. In skills training sessions, you gain practical scientific and engineering experience with the principles and laws of relevant engineering fields as well as imaging applications. Overall, the course provides the basis for you to act as an active participant within the programme and in your development as an imaging engineer.

Course objectives

After completing this course, you are able to:

- Explain fundamental principles of physics, (bio)chemistry and engineering and how they apply to different imaging strategies on different length scales.
- Apply fundamental principles of physics, (bio)chemistry and engineering to explain basic imaging concepts, including:
    - Explaining resolution sensitivity, contrast and image quality for the design of different imagining techniques
    - Dissecting the molecular chemistry and spectroscopy considerations for the design of innovative imaging applications
- Apply imaging and engineering concepts to explain:
    - Which imaging technology is optimal for the spatial challenge presented

    - How imaging quality relates to magnification, resolution, timescale and other imaging parameters for a particular application domain (i.e. food, astronomical, agricultural, clinical, cultural, toxicology, material science etc.)
- Discuss the complementarity between different imaging techniques from an engineering and molecular perspective, and characterise the multidisciplinary nature of the molecular imaging field
- Apply principles and laws of relevant engineering fields / imaging applications and developing basic hands-on experimental and engineering skills
- Act as active participants within the programme and in your development as imaging engineers.

Recommended reading

- Török, P., & Kao, F.J. (2007). Optical Imaging and Microscopy: Techniques and Advanced Systems (2nd ed.). Springer. https://doi.org/10.1007/978-3-540-69565-3
- National Research Council. (2006). Visualizing Chemistry: The Progress and Promise of Advanced Chemical Imaging. National Academies Press.
- Moore, J.H., Davis, C.C., Coplan, M.A., & Greer, S.C. (2009). Building Scientific Apparatus (4th ed.). Cambridge University Press.
- Khandani, S. (2005). Engineering Design Process. Saylor Academy: https://resources.saylor.org/wwwresources/archived/site/wp-content/uploads/2012/09/ME101-4.1-Engineering-Design-Process.pdf

MIE1001
Period 1
2 Sep 2024
25 Oct 2024
Print course description
ECTS credits:
6.0
Coordinator:

- R.M.A. Heeren

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Written exam, Final paper, Presentation
Faculty of Science and Engineering

Imaging Techniques and Instrumentation

Full course description

Imaging technologies find their way into basic research, instrumentation development and applications in an attempt to understand local changes in complex and dynamic systems.

A key element in the selection of an appropriate imaging technology for the research question at hand. Different technologies offer different abilities to study processes from the single cell level (at the nanometre scale) to industrial processes that occur on the scale of meters or more. In some cases, mere morphological information suffices to solve a problem. In other cases, you need

structural molecular information. Advanced imaging techniques such as optical microscopy, cryo-electron microscopy (cryo-EM), mass spectrometry (MS), magnetic resonance imaging (MRI), single-photon emission computerized tomography (SPECT) and positron emission tomography (PET) play an increasingly important role in both academic and industrial research. In this foundational course, you learn about elements of imaging technological choices, comprehensive image capture, data analysis and interpretation to answer research questions associated with molecular imaging in variety of different scientific disciplines. For example, you will be able to select the appropriate imaging technology when presented with a scientific problem where in-vivo and ex-vivo imaging is contrasted with morphological imaging and molecular imaging. This course will thus lay a foundation for the rest of the Master's programme.

Course objectives

After completing this course, you are able to:

- Understand the basic concept and scope of molecular imaging and functional imaging
- Recognise and apprehend different instrumentation components in the different imaging technologies
- Apply fundamental concepts behind each imaging technique to understand how signals are generated, collected and analysed and what molecular information they carry
- Explain critical elements of imaging technological choices, including comprehensive image capture, scale, data analysis and interpretation to answer research questions associated with molecular imaging in variety of different scientific disciplines
- Describe a basic strategy to interpret imaging results
- Work in groups to select and unambiguously motivate an appropriate (molecular) imaging strategy to solve a dynamic and spatially complex problem

Recommended reading

- James, M. L., & Gambhir, S.S. (2012). A molecular imaging primer: modalities, imaging agents, and applications. Physiological reviews, 92(2), 897–965. https://doi.org/10.1152/physrev.00049.2010
- Gilmore, I.S., Heiles, S., & Pieterse, C.L. (2019). Metabolic Imaging at the Single-Cell Scale: Recent Advances in Mass Spectrometry Imaging. Annual Review of Analytical Chemistry, 12, 201-224. https://doi.org/10.1146/annurev-anchem-061318-115516

MIE1002
Period 1
2 Sep 2024
25 Oct 2024
Print course description
ECTS credits:
6.0
Coordinators:

- M.E. Kooi
- R.B. Jolivet

Teaching methods:
Lecture(s), PBL, Skills
Assessment methods:

Molecules and Structures

Full course description

Increasingly, the effect of chemicals (PFAS, Nitrogen) and their properties on our health and biodiversity is discussed. The chemical sciences can be regarded as molecular sciences, covering all types of industrial chemical production processes, pharmaceutical R&D and the design of advanced biomedical materials. In their day-to-day R&D activities, medicinal-, polymer- and analytical chemists, molecular pharmacologists, toxicologists and biomedical scientists, are focussed on the fate of a large diversity of molecules, rely on a in-depth understanding of their structures and more over are familiar with the translation of molecular structures to molecular activity (enzymes) and (physic-chemical) properties. This course is the basis for the molecular engineering track, as interactions, chemical reactions and analytical technologies are highly dependent on molecular thinking.

The structure of molecules can be regarded as a solid fundament of these sciences. For instance, their accurate description, especially their spatial configuration or conformation, forms an essential basis for the assessment of their chemical reactivity/ reaction kinetics, and the related chemical or biological properties. Reaction kinetics in all types of industrial chemical processes or even biologically relevant metabolic pathways are directly related to the molecular structures. Likewise, post translational modifications of proteins altering their spatial conformation have been correlated to disease onset, while chirality has a major impact in the biological efficacy or even toxicity of medicinal drugs. The three-dimensional structure and the binding kinetics of small drug-like molecules is dependent on the positioning or exchange of hetero atoms, e.g. oxygen for sulphur.

The main objective of this course is to revive and deepen the knowledge on the basic descriptors of a large variety of molecular structures, involving industrial chemicals, lipids, steroids, peptides, synthetic and bio-polymers. Likewise, the extensive tools box and the fundamentals of analytical technologies for the unambiguous assessment of their structure will form the second pillar of this course. Equally important is the translation of molecular structures to their related chemical (log P/D) and biological (cell permeability) properties, an essential aspect in the understanding of molecular interactions and biological processes.

Course objectives

After completing this course, you are able to:

- Use basic structure descriptors for the three-dimensional structure assessment of small and large bio- and synthetic molecules, and apply analytical and computational modelling technologies
- Translate molecular structures to basic properties, such as polarity or solubility
- Correlate basic molecular properties to chemical (reactivity) and biological properties (cellular uptake)
- Assess how molecule structures influence molecular interactions and even their role in the design and engineering of chemicals or even (polymeric) materials
- Design and apply different strategies (i.e. which technologies are needed) for the structure assignment of small and large molecules

Imaging Engineering

- Communicate to others the relevance of molecular structures in medicinal or organic chemistry, molecular pharmacology or material sciences.

Recommended reading

Mandatory

- Scientific literature for the literature assignment will supplied by the course coordinator

Recommended

- Yamanouchi, K. (2012). Quantum mechanics of molecular structures (2nd ed.) Springer. https://doi.org/10.1007/978-3-642-32381-2
- Leach, A.R. (2001). Molecular Modelling: Principles and Applications (2nd ed.). Prentice Hall.
- Banwell, C.N., & McCash, E.M. (1994). Fundamentals for Molecular Spectroscopy (4th ed.). McGraw-Hill.

MIE1003
Period 2
28 Oct 2024
20 Dec 2024
Print course description
ECTS credits:
6.0
Coordinators:

- M. Honing
- B. Blom

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Final paper, Written exam
Faculty of Science and Engineering

Imaging Informatics

Full course description

Digital image analysis is one of the fastest growing applications in almost all fields. In automotive industry, self-driving cars will need to interpret images in real time to “see” the children playing next to the street. In public surveillance systems, image analysis will be able to recognize faces from cameras and match them to criminal databases. Satellite imagery will analyse real-time high-resolution satellite images to monitor and predict crop yields. And in the digitalization of industrial production (Industry 4.0), where robots will start replacing more and more skilled workers, image analysis will be needed to enable robots seeing and interpreting their environment.

Also in medicine, digital imaging solutions will continue revolutionizing diagnostic capabilities. In vivo imaging of patients in nuclear medicine departments will provide higher-resolved imaging data accompanied with chemical information to monitor therapy progression. Likewise, digital pathology systems based on high-resolution scans of microscopic slides will use deep learning algorithms to

assist the pathologist in diagnostic decision-making. This is not restricted to the clinical environment. More and more smartphone apps related to health (such as the already existing app for detection of skin cancer using the smart phone camera) will make use of the information provided by the smart phone camera to monitor the health state of the user.

All of these imaging applications will have not only have a high social impact, but will also lead to the creation of new jobs that deal with image analysis. The intention of the course is therefore to prepare you to effectively and successfully analyze digital images, to prepare you for this job market.

Course objectives

After completing this course, you are able to:

- Understand the imaging technology and the characteristics of the image data
    - Image formation;
    - Image representation (pixels/voxels, bit-depths, resolution, colour-maps and colour-models, transparency, vector graphics);
    - Image storage (file formats, compression).
- Develop a fundamental and theoretical understanding of the different algorithms used
    - Logical and arithmetical operations;
    - Simple geometric image manipulation (rotation, scaling);
    - Brightness and contrast adjustments;
    - Colour calibrations;
    - Image filtering;
    - Machine learning approaches (object classification).
    - Image registration to overlay images (control-point based, intensity-based);
    - Spatial statistical tests;
    - 3D imaging data.
- Understand the task/information which needs to be extracted from the images
- Devise an appropriate image processing and analysis pipeline by considering legal and ethical issues in image acquisition and processing
    - Protect privacy and guarantee anonymity of human subjects in image data
    - Digital watermarking of images for copyright protection and authentication
- Develop hands-on image processing / analysis skills
- Improve collaboration and communication skills by working together on a presentation

Recommended reading

- Jähne, B. (2005). Digital Image Processing (6th ed.). Springer. https://doi.org/10.1007/3-540-27563-0
- Bivand, R.S., Pebesma, E. J., & Gomez-Rubio, V. (2013). Applied Spatial Data Analysis with R (2nd ed.). Springer. https://doi.org/10.1007/978-1-4614-7618-4

MIE1004
Period 2
28 Oct 2024
20 Dec 2024
Print course description
ECTS credits:
6.0
Coordinator:

Imaging Engineering

- B.D. Balluff

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Portfolio
Specialisation courses

Specialisation in Instrumentation Imaging Engineering

Faculty of Science and Engineering

Optics and Vacuum Systems

Full course description

Almost all findings in modern astronomy, chemistry, physics, biology, and medicine require data to either establish a hypothesis or verify a conclusion. In most cases, the data in these fields are acquired with an instrument that requires either an optical or a vacuum system (or both).

Almost every scientific instrument related to molecular imaging will employ optics and (if applicable to the molecular imaging technique) vacuum systems. Understanding these methods (and thus how the experiments were performed) usually requires understanding how the relevant optical and vacuum systems work, as well as their limitations and strengths. This course helps you to understand the basic technological concepts related to scientific instrumentation design, read academic methodological papers and improve your comprehension of academic papers that concern vacuum and optical systems.

A continuously active area of research is working to improve these vacuum and optical systems for improved molecular imaging instruments. This course provides you with a foundation in creating optical and vacuum systems, which is needed for future research endeavours such as a PhD or industrial research. In particular, instrumentation manufacturers are in dire need of young engineering professionals that understand the basic concepts of (ion) optics and vacuum system design. Most scientific instruments require at least one of these systems to function. When instrumental problems arise, it is very helpful to have a proper mental model of the optical and vacuum systems of the instrument to help troubleshoot such problems. This course makes you more competent designers, trouble-shooters and academic users in the areas of optical and vacuum systems.

Course objectives

After completing this course, you are able to:

- Develop an accurate mental model of the theoretical underpinnings of optical and vacuum systems used in most commercially-available molecular imaging instruments (e.g. how charged particles behave at different pressures) and especially the interplay between charge particle optics and vacuum systems.
- Apply knowledge of modern (best) practices for vacuum and optical system design, including common system components and interface, and by designing and developing an engineering solution for common problems.

Imaging Engineering

- Critically assess existing optical and vacuum systems and find flaws or areas that should be optimized, by for instance, predicting and estimating the effects that specific changes to a molecular imaging instrument will have on the data collected.
- Use knowledge of the mathematical formulas, principles, and models (e.g., Laplace's equation, Earnshaw's Theorem) used to simulate and design vacuum and optical systems to provide solutions and explanations to unfamiliar problems and systems.
- Apply software to produce simple diagrams of vacuum and optical systems, and to design and simulate charged particle optical experiments that meet a specified set of requirements.

Recommended reading

Mandatory:

Selected readings on vacuum systems and pressure measurement:

- Yoshimura, N. (2008). Vacuum Technology: Practice for Scientific Instruments. Springer. https://doi.org/10.1007/978-3-540-74433-7
- Selected readings for charged particle and light optics:
- Skoog, D.A., Holler, F.J., & Crouch, S.R. (2018). Principles of Instrumental Analysis (7th ed.) Cengage Learning.

Articles to be read in full:

- Wollnik, H. (1999). Ion optics in mass spectrometers. Journal of Mass Spectrometry, 34(10), 991-1006. https://doi.org/10.1002/(SICI)1096-9888(199910)34:10%3C991::AID-JMS870%3E3.0.CO;2-1
- Miller, P.E., & Denton, M.B. (1986). The quadrupole mass filter: Basic operating concepts. Journal of Chemical Education, 63(7), 617-622. https://doi.org/10.1021/ed063p617

Recommended:

The following books, websites, and articles are recommended if you are interested in some of the materials discussed. These are not obligatory for the course and are also not representative of the course (for example, the signal processing portion of the course is very minor, but there are two signal processing resources listed below).

Interactive discussion of the mathematics behind signal processing:

- Schaedler, J. (2020). Seeing Circles, Sines, and Signals: A Compact Primer on Digital Signal Processing. https://jackschaedler.github.io/circles-sines-signals/

In-depth discussion of chemical signal processing:

- O'Hayer, T. (2021). Pragmatic Introduction to Signal Processing: Applications in scientific measurement. https://terpconnect.umd.edu/~toh/spectrum/

Information on vacuum systems at extremely high vacuum:

- Redhead, P.A. (1999). Extreme High Vacuum. In S. Turner (Ed.) Proceedings of the CERN Accelerator School: Vacuum Technology (pp. 213-226). CERN. https://doi.org/10.5170/CERN-1999-005.213

Information on vacuum measurement systems:

Imaging Engineering

- Hansen, S.P. (2009). A primer on vacuum pressure measurement. Vacuum Coating & Technology, 2009(5), 36-42.

Information on outgassing and bake-out:

- Grinham, R., & Chew, A. (2017). A Review of Outgassing and Methods for its Reduction. Applied Science and Convergence Technology, 26(5), 95-109. https://doi.org/10.5757/ASCT.2017.26.5.95

MIE1005
Period 4
27 Jan 2025
28 Mar 2025
Print course description
ECTS credits:
6.0
Coordinator:

- I.G.M. Anthony

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Take home exam, Final paper
Faculty of Science and Engineering

Detectors and Electronics

Full course description

The James Webb Space Telescope, a cell phone's camera, an FMRI instrument, an electron microscope, and an imaging mass spectrometer are all imaging devices that take pictures that can provide us data to better make decisions. Although there are many differences between these devices, all of them employ a source, the illumination of a sample, and record a signal from that illumination using a detector and electronics.

Understanding how Detectors and Electronics work will empower you to design and adapt detectors and electronics to solve problems. Moreover, understanding how digital data is acquired, and possibly altered by electronics, will empower you to avoid common pitfalls in interpreting and processing your data.

This course will help you develop basic electronic skills such as operating oscilloscopes, designing measurement setups, and good circuit design practices. Additionally, you will combine these practical skills with in-depth theoretical and practical knowledge of advanced electronics and signal acquisition. This course will also help you understand the electrical and chemical basis for imaging detectors such as MAPS, CMOS, hybrid-pixel detectors, conversion dynodes, and other camera systems. As not only the capturing instrumentation but also digital processing limit the quality of data, including images, this course will cover introductory signal processing material.

By the end of this course, you will have a solid foundation in understanding both the creation and application of Detectors and Electronics, which is essential for research in fields such as digital signal processing and instrument development. The skills and competencies you develop in this

course range much further, however. By understanding the principles and electrical components in imaging systems, you will develop a deeper understanding of all imaging systems, from cameras to imaging mass spectrometers. This course will improve your ability to work with all imaging systems — from using your cell phone camera to fixing an electron microscope — by enabling you to more rapidly troubleshoot data acquisition or electrical problems and to better optimize your imaging experiments.

Course objectives

After completing this course, you are able to:

- Apply electronics concepts such as amplifiers, filters, digital logic, impedance, and capacitance and understand their importance in imaging
- Understand different detector technologies like CMOS, CCD, photomultiplier tubes, and simple non-imaging based sensors and be able to communicate their relative strengths and weaknesses
- Use microcontrollers to interface with different sensors to acquire data
- Design, test, and understand circuits that are similar to the advanced electronics in high-end imaging equipment
- Present and communicate circuit designs and their relationship to image acquisition and processing technology to an audience.

Recommended reading

Mandatory literature:

Selected mandatory readings from books and academic papers on detectors and electronics will be provided through Canvas.

Recommended:

- Scherz, P., & Monk, S. (2013). Practical Electronics for Inventors (3rd ed.). McGraw-Hill Education.
- Schaedler, J. (2020). Seeing Circles, Sines, and Signals: A Compact Primer on Digital Signal Processing. https://jackschaedler.github.io/circles-sines-signals/
- Skoog, D.A., Holler, F.J., & Crouch, S.R. (2018). Principles of Instrumental Analysis (7th ed.) Cengage Learning.
- Ben Eater’s YouTube series on digital electronics is highly useful. Concerning analog circuits, Dave Jones’ Youtube series on electronics tutorials has many videos that are useful for the electronics concepts. Fundementals Friday covers many electronics basics. Electronics Tutorials has many useful videos as well, although there are also some that don’t apply to the material in this course.
- Eater, B. (2015). Digital electronics tutorial [Video playlist]. YouTube. https://www.youtube.com/playlist?list=PLowKtXNTBypETld5oX1ZMI-LYoA2LWi8D
- Jones, D. (2021). Fundamentals Friday [Video playlist] YouTube. https://www.youtube.com/playlist?list=PLvOlSehNtuHtWlH0UOZNtOn-FlFCn1GYw
- Jones, D. (2021). Electronics Tutorials [Video playlist] YouTube. https://www.youtube.com/playlist?list=PLvOlSehNtuHtWlH0UOZNtOn-FlFCn1GYw

MIE1009
Period 5

Imaging Engineering

31 Mar 2025
23 May 2025
Print course description
ECTS credits:
6.0
Coordinators:

- B.R.N. van Grinsven
- I.G.M. Anthony

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Computer test, Presentation
Faculty of Science and Engineering

Integrative Imaging Systems Design

Full course description

Integrative imaging systems design is an interdisciplinary field of engineering that focuses on how to design and engineer complex imaging systems such as hyperspectral astral photography satellites and hybrid molecular imaging instruments. It is the ultimate tool for the rapid translation of scientific instrumentation into competitive new products. Imaging instrumentation is in a continuous state of evolution. In this course, you develop knowledge and insights of the instrumentation engineering principles needed to make useful and creative decisions in the design and construction of cutting-edge imaging instrumentation. You also develop expertise with the engineering design cycle within the context of scientific (imaging) instrumentation. This design cycle encompasses the analysis and formulation of the instrumentation design problem, setting design requirements, generating several conceptual designs followed by the selection of the optimal solution and its realization. Upon completion, you are able to identify and explain the process steps in scientific instrumentation design, modelling, and engineering. Special attention is paid to the underlying scientific principles and laws of the scientific instrumentation innovation as well as the elementary modelling steps of engineering systems.

Course objectives

After completing this course, you are able to:

- Use and discuss the importance of CAD (i.e. Creo Parametric) to integrative imaging system design.
- Develop the (engineering) skills needed to perform comprehensive problem analysis with defined quantitative requirements.
- Design an integrated imaging system using CAD and support the design with theoretical knowledge, calculations and simulations.
- Critically assess solutions (both your own and others) and work to refine existing (or previously developed) imaging solutions.
- Grasp the growing need and broader context for integrative imaging solutions.

Imaging Engineering

Recommended reading

Mandatory:

- Khandani, S. (2005). Engineering Design Process. Saylor Academy: https://resources.saylor.org/wwwresources/archived/site/wp-content/uploads/2012/09/ME101-4.1-Engineering-Design-Process.pdf
- Hall, A. S., Lavery, L. L., & Doux, P. (2018). Effective Multimodal Multiscale Analytical and Imaging Correlation. IEEE Sensors Letters, 3(1), 1-4. https://doi.org/10.1109/LSENS.2018.2878667
- Walter, A., Paul-Gilloteaux, P., Plochberger, B., Sefc, L., Verkade, P., Mannheim, J. G., ... & Wanek, T. (2020). Correlated Multimodal Imaging in Life Sciences: Expanding the Biomedical Horizon. Frontiers in Physics, 8, 1-28. https://doi.org/10.3389/fphy.2020.00047

Recommended:

- Skoog, D.A., Holler, F.J., & Crouch, S.R. (2018). Principles of Instrumental Analysis (7th ed.) Cengage Learning.

MIE2001
Period 1
2 Sep 2024
25 Oct 2024
Print course description
ECTS credits:
6.0
Coordinator:

- A. Mathew

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Portfolio, Presentation

Specialisation in Molecular Imaging Engineering

Faculty of Science and Engineering

Process Analytical Technologies

Full course description

In nearly all manufacturing processes the safety and quality (control) assessment of the intermediate and end products is of crucial economic or even safety importance. Hence, where before the nineties of the last century the quality of all product was verified at the end of the production lane, nowadays continuous quality control in the entire production process is common practice. This approach has led to considerable time saving, and above all substantial reduction of so-called “out-of-specification” products.

Process analytical technologies (PAT) and their application are referred to as all technologies and approaches in the continuously monitoring of such production process. In particular, in chemical

industry temperature of pressure sensors are used for the control of the processes. Likewise, in the most cell-based production processes of biopharmaceuticals the quality of the medium requires continuous monitoring. The continuous following on exothermic chemical reactions is crucial to prevent “run-away-reactions” being a pivotal safety assurance. PAT sciences encompass traditionally many miniaturized spectroscopic technologies, relying on fast readout of in many cases digital data, and a fundamental understanding of the production process in itself.

The main objective of this course is to deepen the knowledge on the basics of process technologies, its fundamentals, the essential technologies and their impact in process control and quality.

Course objectives

After completing this course, you are able to:

- Understand the basic concept of processing in (industrial) chemistry and biotechnology – the role of Process Analytical Technologies.
- Design sampling strategies and calibration approaches and discuss the control of out-of-equilibrium processes and control of processes.
- Utilize basic chemometric tools combined with novel artificial technology techniques for effective data handling and process understanding.
- Evaluate different quality and safety by design concepts.
- Design and utilization of monitoring and detection strategies utilizing a combination of (miniaturized) sensor technologies in e.g. flow chemistry.

Recommended reading

- Bakeev, K.A. (Ed.). (2010). Process Analytical technology: Spectroscopic Tools and Implementation Strategies for the Chemical and Pharmaceutical Industries (2nd ed.). Wiley.
- Skoog, D.A., West, D.M., Holler, F.J., & Crouch, S.R. (2014). Fundamentals of Analytical Chemistry (9th ed.). Cengage learning.
- Miller, J.N., Miller, J.C., & Miller, R.D. (2018). Statistics and Chemometrics for Analytical Chemistry (7th ed.). Pearson.

MIE2002
Period 1
2 Sep 2024
25 Oct 2024
Print course description
ECTS credits:
6.0
Coordinator:

- M. Honing

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Final paper, Written exam, Assignment
Faculty of Science and Engineering

Molecular Interactions

Full course description

The non-covalent interactions between molecules, or the interactions between “functional groups” within larger (bio) polymers form the basis of molecular imaging engineering, in particular to correctly measure and understand the mechanism behind agents’ activation. As an example, the widely applied fluorescent labels in histopathology or detection of molecules in functionalized materials is strongly influenced by their interactions with other molecules in their surroundings. Moreover, understanding these interaction is essential for practical applications like the discovery of new drugs, the (biotechnological) production of bio-pharmaceuticals like insulin or the preparation of (bio) polymeric materials, etc

Many molecules act in combination with others, e.g. proteins in the blood compartment transport medicinal drugs or nutritional compounds. Likewise, the “amorphous” or “crystalline” nature of polymer thermoplastics (polyamides) have a direct relation to the molecular weight dispersity of these polymers. The interaction between small molecular drugs with protein drug targets is in most cases “non-covalent” in nature, and the causality between changing three-dimensional morphology” of complex supra molecular complexes like Apo lipoproteins with the progression of diabetes type I has been confirmed. Hence, the rate of formation, the stability and morphology of aggregates directly relates to the molecular structure of the “separate” building blocks, and as such and importance next step in understanding the impact of molecular structures in e.g. food industry (dairy products).

The main objective of this elective course is deepening the knowledge on non-covalent inter- and intramolecular interactions, creating insight into the fundamentals forces involved, the mechanism responsible for the formation of e.g. supramolecular complexes (self-assemblies of proteins) and the technologies able to identify the interaction kinetics and morphologically structure of the complexes.

Course objectives

After completing this course, you are able to:

- Understand the basic physical molecular forces underlying the kinetics of molecular interactions, stability and morphology of molecular complexes.
- Explain to others the basic mechanisms underlying protein folding & formation of biologically relevant supra molecular complexes (Apo lipoproteins)
- The ability to utilize different analytical technologies for small molecule and polymer crystallization processes and present the selected analytical strategy.
- Define strategies in utilizing different analytical technologies for the assessment of interaction kinetics and the structure of molecular complexes.
- Build on a basic experience with molecular modelling and homology models.
- Discuss and present among peers, the essentials of molecular interactions in drug discovery, polymer and food processing.

Recommended reading

Recommended

- Micha, D. A. (2019). Molecular Interactions: Concepts and Methods. Wiley. https://doi.org/10.1002/9781119319085
- Karshikoff, A. (2006). Non-Covalent Interactions in Proteins. Imperial College Press. https://doi.org/10.1142/p477
- Jhoti, H., & Leach, A.R. (Eds.). (2007). Structure-Based Drug Discovery. Springer. https://doi.org/10.1007/1-4020-4407-0

MIE1006
Period 4
27 Jan 2025
28 Mar 2025
Print course description
ECTS credits:
6.0
Coordinators:

- I. Dijkgraaf
- M. Honing

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Final paper, Written exam
Faculty of Science and Engineering

Molecular Engineering for Imaging

Full course description

The engineering of molecules, traditionally called organic synthesis, has evolved from classical batch type reaction sequences to highly advanced flow-based processes and is a vibrant dynamic scientific area. Ranging from the syntheses of peptides, complex glycan’s and modified proteins to functionalized monoclonal antibodies, smart materials and all the way to the molecular engineering of smaller building blocks, fine-chemicals and novel medicinal drugs. Often both methodology as well as targeted molecules are inspired by Nature, be it bio-inspired synthesis or natural products. The design, route scouting and availability of many of the highly innovative new technologies justifies the term “molecular engineering”.

Another important driving force in molecular engineering is to adopt sustainable “green” synthesis alternatives as an economically viable means to produce high-added-value materials, medicines, imaging probes and catalysts. In this light, flow-chemistry and new flow-reactor design have emerged as powerful enabling tools to discover next level molecular engineering methods in photo, electro and plasma chemistry, as well as one-pot synthesis strategies and bio-, organo- and base-metal catalysis.

Evidently, molecular engineering has positioned itself as an important scientific domain in biology, pharmaceutical and base chemical industry, biotechnology, agriculture and food industry.

The main objective of this course is to revive and deepen the basis in advanced organic synthesis, including new developments like (flow) reactor design, (bio)-catalysis, photochemistry (synthetic

polymers) and chemical modification of biopolymers. Retrosynthetic analysis, Natural product chemistry and bio-inspired synthetic methodology will be at the heart of this course in order to reach –out to the advanced application areas discussed above.

Course objectives

After completing this course, you are able to:

- Understand the basic processes in advanced chemical synthesis and able to evaluate or design efficient (yield, selectivity) and cost effective (green) synthesis routes.
- Explain principles in the design of stereo- and region selective chemical synthesis routes.
- Design and evaluate optimal batch or flow-reactors, based on a basic knowledge of reactor engineering.
- Understand and apply photo- & electro chemically directed chemical conversions in e.g. flow-reactors and evaluate the utility of bio-catalysis as well as other advanced catalytic processes in the industrial chemistry.
- Design and evaluate advanced multistep synthesis routes for the chemical creation and/or modification / functionalization of e.g. biopolymers, monoclonal antibodies, imaging tools and other advanced high-added-value molecules.
- Integrate insights from literature in designing total synthesis routes
- Write and defend a research proposal, as well as reviewing a proposal by offering critical feedback.

Recommended reading

Mandatory:

- Clayden, J., Greeves, N., & Warren, S. (2012). Organic Chemistry (2nd ed.). Oxford University Press.
- Lecture slides and additional literature will be provided to complement this textbook.

Recommended:

- Carey, F. A., & Sundberg, R. J. (2007). Advanced Organic Chemistry: Part A: Structure and Mechanisms (5th ed., Vol. A). Springer. https://doi.org/10.1007/978-0-387-44899-2
- Carey, F. A., & Sundberg, R. J. (2007). Advanced Organic Chemistry: Part B: Reactions and synthesis (5th ed., Vol. B). Springer. https://10.1007/978-0-387-71481-3
- Wardle, B. (2009). Principles and Applications of Photochemistry. Wiley.
- Mann, U. (2009). Principles of Chemical Reactor Analysis and Design: New Tools for Industrial Chemical Reactor Operations (2nd ed.). Wiley. https://doi.org/10.1002/9780470385821
- Darvas, F., Dorman, G., & Hessel, V. (Eds.) (2014). Flow Chemistry: Organic Synthesis in Motion: Fundamentals (Vol. 1). Walter de Gruyter. https://doi.org/10.1515/9783110289169
- Faber, K. (2018). Biotransformations in Organic Chemistry: A Textbook (7th ed.). Springer. https://doi.org/10.1007/978-3-319-61590-5
- Aehle, W. (Ed.). (2007). Enzymes in Industry: Production and Applications (3rd ed.). Wiley. https://doi.org/10.1002/9783527617098
- Giese, B.M., Pade, C., Wigger, H., & von Gleich, A. (Eds.). (2015). Synthetic Biology: Character and Impact. Springer. https://doi.org/10.1007/978-3-319-02783-8

MIE1010
Period 5

Imaging Engineering

31 Mar 2025
23 May 2025
Print course description
ECTS credits:
6.0
Coordinator:

- R.V.A. Orrù

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Final paper
Projects

Projects

Faculty of Science and Engineering

Research and Engineering Project I

Full course description

The two research projects within the MSc Molecular Imaging & Engineering (PRO4004 and PRO4005) offer you an opportunity to mature, integrate and apply your acquired knowledge, insight and skills. The projects allow you to develop practical experience in developing an experimental set up to study a research question (engineering), setting up and conducting a proper experiment to answer a research question (scientific research) in the molecular imaging domain.

You will work within a team and collaborate with internal and/or external [1] research groups in academia or industry. The real-life nature of the projects is the result of the involvement of Maastricht University research groups and companies, (non-)profit organisations and research institutes hosted at the Brightlands Campuses [2]. The interaction between you, teaching staff, research groups and company members, is beneficial to your learning and connections for future internships and employment, but also beneficial to the research groups and companies who can profit from your views and state-of-the-art input. Each project has a small deviation in focus. In the project at the end of the first semester (PRO4004), additional aspects such as intellectual property and valorisation will be part of the project. At the end of the second semester (PRO4005), the focus of the project will be in the domain of the chosen specialisation.

[1] “External” refers to Maastricht University research groups, research institutes, companies and (non-) profit organisations.

[2] Collaboration is not strictly bounded to parties affiliated with the Brightlands Campuses. We merely can guarantee that projects will be offered by the Brightlands Campuses due to our existing collaboration.

Course objectives

After completing this course, you are able to:

1. Plan and perform a group-led high-level scientific research project in the pertaining field. This includes:

• _Working together to analyze scientific problems/engineering challenges.

• _Making use of relevant specialist literature and formulating verifiable hypotheses.

• _Setting up and carrying out (as a group) research to test a scientific hypothesis.

2. Work and communicate effectively in a team by participating as an active member of a multidisciplinary research group. This includes:

• _Deciding on appropriate role and task division, which leads to effective team work.

• _Managing the group work within the provided time by setting deadlines/milestones, choosing if and how to meet, and choosing how to share/ store/ collaborate on the work.

• _Working autonomously on a research project with less formal supervision

3. Implement the scientific method and/or R&D professional practices by:

• _Writing hypotheses, collecting, and analyzing data, and troubleshooting where needed.

• _Solving a problem in a multi-disciplinary way, using all the groups' knowledge, competences, and skills.

4. Critically reflect on and evaluate research work quality, group work, and scientific ethics and make improvements as necessary. This includes:

• _Performing constructive peer review on (part) products or contribution of group members

• _Performing constructive peer review on (part) products or contribution of group members

• _Integrating provided feedback (project 1 and 2) into the final product.

• _Identifying areas for improvement during the process of groupwork

5. Effectively communicate science both in writing through a written report describing the results, conclusions and the relevance of the conducted research, and orally in a final presentation. This includes:

• _Evaluating research results,

• _Communicating and defending these results verbally and in writing and discussing their societal relevance.

• _Writing and defending a comprehensive report (report results of the project).

• _Presenting the results for a wide public.

Recommended reading

Regardless the nature of your assignment, you can benefit from recap of the generic engineering cycle and/or the experimental research cycle. Below is a selection that covers theses cycles, but you are welcome to use other sources. Also included is a book that covers each section of academic writing with many useful tips, especially to write the results and discussion sections.

- Khandani, S. (2005), Engineering design process.
- Tanner (2002), Experimental research designs.
- Swales JM, Peak CB (2012), Academic Writing for Graduate Students, 3rd ed. University of Michigan Press

PRO4004
Period 3
6 Jan 2025
24 Jan 2025
Print course description
ECTS credits:
6.0
Coordinator:

- S.P.M. van Nuffel

Teaching methods:
Research
Assessment methods:
Final paper, Presentation
Faculty of Science and Engineering

Research and Engineering Project II

Full course description

The two research projects within the MSc Molecular Imaging & Engineering (PRO4004 and PRO4005) offer you an opportunity to mature, integrate and apply your acquired knowledge, insight and skills. The projects allow you to develop practical experience in developing an experimental set up to study a research question (engineering), setting up and conducting a proper experiment to answer a research question (scientific research) in the molecular imaging domain.

You will work within a team and collaborate with internal and/or external [1] research groups in academia or industry. The real-life nature of the projects is the result of the involvement of Maastricht University research groups and companies, (non-)profit organisations and research institutes hosted at the Brightlands Campuses [2]. The interaction between you, teaching staff, research groups and company members, is beneficial to your learning and connections for future internships and employment, but also beneficial to the research groups and companies who can profit from your views and state-of-the-art input. Each project has a small deviation in focus. In the project at the end of the first semester (PRO4004), additional aspects such as intellectual property and valorisation will be part of the project. At the end of the second semester (PRO4005), the focus of the project will be in the domain of the chosen specialisation.

[1] “External” refers to Maastricht University research groups, research institutes, companies and (non-) profit organisations.

[2] Collaboration is not strictly bounded to parties affiliated with the Brightlands Campuses. We merely can guarantee that projects will be offered by the Brightlands Campuses due to our existing collaboration.

Course objectives

After completing this course, you are able to:

1. Plan and perform a group-led high-level scientific research project in the pertaining field. This includes:

• _Working together to analyze scientific problems/engineering challenges.

• _Making use of relevant specialist literature and formulating verifiable hypotheses.

• _Setting up and carrying out (as a group) research to test a scientific hypothesis.

2. Work and communicate effectively in a team by participating as an active member of a multidisciplinary research group. This includes:

• _Deciding on appropriate role and task division, which leads to effective team work.

• _Managing the group work within the provided time by setting deadlines/milestones, choosing if and how to meet, and choosing how to share/ store/ collaborate on the work.

• _Working autonomously on a research project with less formal supervision

3. Implement the scientific method and/or R&D professional practices by:

• _Writing hypotheses, collecting, and analyzing data, and troubleshooting where needed.

• _Solving a problem in a multi-disciplinary way, using all the groups’ knowledge, competences, and skills.

4. Critically reflect on and evaluate research work quality, group work, and scientific ethics and make improvements as necessary. This includes:

• _Performing constructive peer review on (part) products or contribution of group members

• _Performing constructive peer review on (part) products or contribution of group members

• _Integrating provided feedback (project 1 and 2) into the final product.

• _Identifying areas for improvement during the process of groupwork

5. Effectively communicate science both in writing through a written report describing the results, conclusions and the relevance of the conducted research, and orally in a final presentation. This includes:

• _Evaluating research results,

• _Communicating and defending these results verbally and in writing and discussing their societal relevance.

• _Writing and defending a comprehensive report (report results of the project).

• _Presenting the results for a wide public.

Recommended reading

Regardless the nature of your assignment, you can benefit from recap of the generic engineering cycle and/or the experimental research cycle. Below is a selection that covers theses cycles, but you are welcome to use other sources. Also included is a book that covers each section of academic writing with many useful tips, especially to write the results and discussion sections.

- Khandani, S. (2005), Engineering design process.
- Tanner (2002), Experimental research designs.
- Swales JM, Peak CB (2012), Academic Writing for Graduate Students, 3rd ed. University of Michigan Press

PRO4005
Period 6
26 May 2025
13 Jun 2025
Print course description
ECTS credits:
6.0
Coordinators:

- M. Honing
- I.G.M. Anthony

Teaching methods:
Research
Assessment methods:
Final paper, Presentation
Elective courses

Elective courses

Faculty of Science and Engineering

Advanced Image Processing and AI

Full course description

“A picture is worth a thousand words”. Most of us humans are much more efficient in conveying ideas and messages through pictures than through words. For a computer, this is not such an easy task. Tasks like face recognition have been worked on for more than 50 years, but became only recently available on mobile devices. A computer will require a multitude of steps before it can crap the essence of a picture. The high-resolution imaging modalities used in the field of Molecular Imaging and Engineering inevitably require automated analysis methods. In recent years these have

become increasingly sophisticated, requiring expert knowledge to implement successfully.

This course will build on the fundaments laid out in the Imaging Informatics course and bring imaging processing to a next level. Although the professional context of this course is geared towards the applications offered during the programme, the methods presented are used for a wide range of modern-day image recognition, classification tasks, among others. Their fundamental aspects serve a much broader perspective, given the wide social impact that automated image recognition has on the society now and in the decades to come.

Course objectives

After completing this course, you are able to:

- Explain basic mathematical concepts such as complex numbers, derivatives & integrals, geometric series, trigonometric & exponential functions and apply them to Fourier sums, Fourier 2D and 3D transforms, Parseval's theorem and (bandpass) filters.
- Design & practice computational image processing implementations, including applying and developing MATLAB code for image processing.
- Use image-processing techniques such as Noise filtering, Wiener filtering, inverse filtering, geometric transformations and grey value interpolation.
- Calculate the Nyquist-frequency and predict how to prevent aliasing
- Solve problems in multi-modal imaging and to segment image data by feature recognition both via neural network training techniques as well as through more traditional morphological image processing techniques.
- Consider ethical issues in image processing and communicate related considerations to an audience of specialists and non-specialists.

Recommended reading

- Anton, H., & Rorres, C. (2013). Elementary Linear Algebra: Applications Version (10th ed.). Wiley.
- Neuhauser, C., & Roper, M. L. (2018). Calculus for Biology and Medicine (4th ed.). Pearson.
- Bodine, E. N., Lenhart, S., & Gross, L. J. (2014). Mathematics for the Life Sciences. Princeton University Press.
- Jähne, B. (2005). Digital Image Processing (6th ed.). Springer. https://doi.org/10.1007/3-540-27563-0
- Bivand, R.S., Pebesma, E. J., & Gomez-Rubio, V. (2013). Applied Spatial Data Analysis with R (2nd ed.). Springer. https://doi.org/10.1007/978-1-4614-7618-4
- Gonzalez, R.C., & Woods, R.E. (2018). Digital Image Processing (4th ed.). Pearson.
- Gonzalez, R.C., Woods, R.E., & Eddins, S.L. (2020). Digital Image Processing using MATLAB (3rd ed.). Pearson.
- Forsyth, D.A., & Ponce, J. (2012). Computer Vision: A Modern Approach (2nd ed.). Pearson

MIE1007
Period 4
27 Jan 2025
28 Mar 2025
Print course description
ECTS credits:
6.0
Coordinator:

Imaging Engineering

- S.P.M. van Nuffel

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Computer test
Faculty of Science and Engineering

Advanced Optical Microscopy

Full course description

Light is defined as the visible spectrum of the electromagnetic radiation, between 450-700 nm. Therefore, light microscopy refers to techniques that use this part of the spectrum. Light cannot penetrate too deep into matter, compared to magnetic fields and ultrasound, but can offer good resolution, up to 20 nm and is not damaging to living tissue.

Light microscopy is a standard method in any Research & Development lab setting. It has found applications in numerous diverse fields such as medicine and biology to chemistry and material sciences. Microscopic findings are very often presented in scientific papers as well as information media such as the internet, newspapers, and television. However, to be able to critically assess observed or published parameters, it is crucial to understand how a certain microscopy technique works and to understand its specific advantages, disadvantages, and limitations. Only then you will be able to interpret correctly what you see or read. Additionally, before you do microscopy experiments yourself, requires to be able to weigh the correct methods of imaging and arrive at the optimal technique to be used. Finally, you have to be able to judge needed adaptations to the microscope you plan to use.

Course objectives

After completing this course, you are able to:

- Explain the basic physics principles of light microscopy, such as image formation and resolution.
- Describe various types of light microscopes, their design principles as well as their fields of application.
- Work with various components of microscopes and calculate their optical characteristics and adaptations.
- Prepare and stain samples for imaging by understanding and applying the underlying principles.
- Operate a commercial microscope, acquire images, and process them using standard imaging software.
- Design suitable microscopic experiments for a specific biomedical application and optimize the imaging setup.
- Discriminate and critically assess basic, established, and pilotal microscopy techniques.
- Discuss and assess (technical) choices and adaptations to specific imaging situations within your peer group and in lays terms.

Imaging Engineering

Recommended reading

Mandatory

- Mandatory literature will be communicated during the course to ensure the latest literature and developments.

Recommended

Feel free to approach the coordinator to suggest additional books/articles if you are interested in specific topics and/or desire to have more information, or check the literature below:

- Mertz, J. (2019). Introduction to Optical Microscopy. Cambridge University Press. https://doi.org/10.1017/9781108552660
- Murphy, D. B. (2012). Fundamentals of Light Microscopy and Electronic Imaging (2nd ed.). Wiley. https://doi.org/10.1002/9781118382905

MIE1008
Period 4
27 Jan 2025
28 Mar 2025
Print course description
ECTS credits:
6.0
Coordinator:

- D. Kapsokalyvas

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Portfolio, Presentation
Faculty of Science and Engineering

Mass Spectrometry Imaging

Full course description

Mass spectrometry is a versatile analytical tool with applications in many scientific disciplines. It can ionise molecules from various sample classes, separate these ions and their fragment ions according to their specific mass-to-charge ratio (m/z), and finally record the relative abundance of each ion type that reaches the detector. Mass spectrometry thus enables the qualitative and quantitative analysis of thousands of molecular compounds in a single experiment without the need for labelling and is particularly powerful for the structural identification of unknown compounds. These compounds include basic chemicals, small molecules and also large polymers. In the biosciences, it can be used to detect drugs, exogenous and endogenous metabolites, lipids, peptides, proteins and other (bio)polymers. In particular, mass spectrometry imaging is an innovative and dynamic methodology that can not only detect molecules label-free but also visualise their spatial distribution in 2D and 3D with high resolution. Therefore, it is increasingly used in various disciplines in both academia and industry. In this course, you will be trained as highly skilled scientists to innovate and apply MS based imaging to scientific research ranging from healthcare, performance materials, agro/food science, and semiconductor technology. This will be a highly desired skill set in future

careers at research institutes, medical university centres, biomedical companies, etc.

Course objectives

After completing this course, you are able to:

- Explain basic principles of mass spectrometry (imaging) such as mass resolution and lateral / spatial resolution;
- Understand the fundamentals behind the design of various mass analysers such as underlying ionization techniques, mass analysers and detectors. In addition, you will learn to assess which design fits certain imaging scenarios best;
- Distinguish the different methodologies for the structural characterization of biologically and chemically relevant molecules;
- Design protocols and experiments, and make a plan for the application of biomedical imaging to different research questions;
- Prepare calibration & response curves to test and tune performance for a variety of mass spectrometers;
- Handle samples for MS imaging of human/animal tissue or biomedical materials;
- Interpret, process and manage MS data originating from imaging, ion mobility spectrometry and tandem mass spectrometry experiments with help of advanced statistical and data processing software;
- Work in a team and be able to convey scientific results to both experts and the public.

Recommended reading

- Mass spectrometric imaging for biomedical tissue analysis. Chughtai K, Heeren RM. Chem Rev. 2010 May 12;110(5):3237-77. doi: 10.1021/cr100012c. PMID: 20423155
- Going forward: Increasing the accessibility of imaging mass spectrometry. McDonnell LA, Heeren RMA, Andrén PE, Stoeckli M, Corthals GL. J Proteomics. 2012 Aug 30;75(16):5113-5121. doi: 10.1016/j.jprot.2012.05.016. PMID: 22634082
- Analysis of tissue specimens by matrix-assisted laser desorption/ionization imaging mass spectrometry in biological and clinical research. Norris JL, Caprioli RM. Chem Rev. 2013 Apr 10;113(4):2309-42. doi: 10.1021/cr3004295. PMID: 23394164
- Reshaping Lipid Biochemistry by Pushing Barriers in Structural Lipidomics. Porta Siegel T, Ekroos K, Ellis SR. Angew Chem Int Ed Engl. 2019 May 13;58(20):6492-6501. doi: 10.1002/anie.201812698. PMID: 30601602
- Multimodal Imaging Based on Vibrational Spectroscopies and Mass Spectrometry Imaging Applied to Biological Tissue: A Multiscale and Multiomics Review. Tuck M, Blanc L, Touti R, Patterson NH, Van Nuffel S, Villette S, Taveau JC, Römpp A, Brunelle A, Lecomte S, Desbenoit N. Anal Chem. 2021, 93, 1, 445–477.

MIE1011
Period 5
7 Apr 2025
6 Jun 2025
Print course description
ECTS credits:
6.0
Coordinator:

- E. Cuypers

Imaging Engineering

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Written exam, Presentation
Faculty of Science and Engineering

Electron Microscopy

Full course description

Electron microscopy (EM) is currently the imaging technique providing the highest resolution in objects. The resolution that can be reached today is sub-atomic for hard materials and atomic for biological specimens. Different types of electron microscopes are adapted in their configuration to different type of samples and different type of applications. The applications of the EM in situ atomic resolution go from deciphering the structure of proteins key for all genetic diseases and infections, to characterizing the composition of nanomolecular machines in its normal and aberrant form in order to make new drug and or vaccines based on 3D structural information.

In this course, the EM applications targeted are mainly in the fields of life sciences and medicine. The possibility of studying the fine three-dimensional structure of proteins in their natural environment, the cells, where they are working in a dynamic manner with many other biomacromolecules, makes the electron microscope an essential and very powerful tool to aid in the search for new therapeutic targets and new treatments like drugs or vaccines against the molecules responsible for a disease. The cell functions are the result of the combination of the work of thousands of different proteins with each other and with other molecules and this can only be analysed using an in situ high-resolution technique preserving the small crowded cellular environment where all these molecules work together. Cryo-electron microscopy makes this possible. At the same time, applying different EM techniques, it is possible to describe the cellular characteristics in tissues where the proteins are playing their role.

However, not only medicine can benefit from EM but also animal, plant cells, bacteria and viruses are being characterized by EM. The role of certain molecules involved in many cellular events can be addressed by high resolution imaging techniques providing crucial information to agricultural and environmental studies. The electron microscope is a very powerful and necessary tool for the investigations of new biological models replacing the use of animal experiments. Mini-organs (organoids), cellular aggregates, artificial tissues etc. are now under development and will be the future support of the biological and medical research.

EM is a field in continuous and very fast expansion. Other professional areas closely connected to EM developments are engineering, informatics, image processing, data management, machine learning and artificial intelligence. These professional fields will benefit from the knowledge acquired in this course.

Course objectives

After completing this course, you are able to:

- Explain basic principles of EM instrumentation:
- Transmission electron microscopy (TEM), scanning electron microscopy (SEM), STEM, focused ion beam SEM microscopy (FIB-SEM), use of different electrons acceleration voltage in TEM and SEM, use of contrast strategies, use of low irradiation techniques, use of electron

diffraction, use of CCD detectors and electrons direct detector devices (DDD) and coating techniques for the FIB work.
- Utilise specific techniques of recording:
- Automation of 2D projection, single particle data acquisition, tomography, single tilt, block face SEM and Slicing and imaging. All at room temperature and at cryogenic conditions.
- Prepare samples and apply molecular labelling techniques to reach all information from samples:
- Chemical fixation and room temperature dehydration and embedding, ultramicrotomy, Tokuyasu cryo-sectioning, vitrification by plunge freezing, jet freezing and high pressure freezing, cryo-lamella fabrication, freeze-substitution, immunolabelling).
- Analyse and process acquired data
- Single particle analysis, helical reconstruction, tomographic reconstruction, subtomogram averaging and 3D volume imaging techniques.
- Work in teams to select the right type of EM instrument and demonstrate an innovative attitude by defining a (novel) technique for specific problems.

Recommended reading

Recommended

Recent methodological literature regarding electron microscopy will be provided in lectures and tutorials. The following books are recommended if you are interested in specific topics and/or desire to have more information:

- Hawkes, P. W., & Spence, J. C. (Eds.). (2019). Springer Handbook of Microscopy. Springer. https://doi.org/10.1007/978-3-030-00069-1
- Egerton, R. F. (2005). Physical Principles of Electron Microscopy (2nd. ed). Springer. https://doi.org/10.1007/978-3-319-39877-8
- Goodhew, P.J., Humphreys, J., & Beanland, R. (2000). Electron Microscopy and Analysis (3rd ed). Taylor & Francis.

Software

- RELION
- MATLAB
- Coot

MIE1012
Period 5
31 Mar 2025
23 May 2025
Print course description
ECTS credits:
6.0
Coordinator:

- K. Knoops

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Written exam

Imaging Data Management

Full course description

Modern imaging technologies have the potential to create vast amounts of imaging data. The imaging professional must understand how to cope with the 4Vs of big data: Volume, Variety, Velocity, and Veracity. The volume of data refers to the size of data that needs to be processed and analysed, and the working professional must be prepared to work with data sizes that range from megabytes to petabytes. The velocity of data refers to the speed at which data are generated, and one must understand how to build pipelines that can scale with the amount of data coming in at any one time. The variety of data refers to the different ways that data are structured – this includes unstructured data such as text, semi-structured data such as data records, and structured data available in standardized data formats. Finally, the veracity of data refers to the quality of data which can affect the whether results can be obtained or whether any meaningful interpretation can be made from the analysis. Overall, this course provides you with a deep understanding of the opportunities, challenges, and practical concerns in working with different kinds of imaging data.

Course objectives

After completing this course, you are able to:

- Explain how images are represented on a computer and what imaging standards are available to store, retrieve and process images.
- Be able to describe, contrast, and use prevalent imaging metadata standards.
- Understand the merits of different imaging platforms (e.g. XNAT) in working with large imaging datasets, and use such platforms in data storage and retrieval.
- Describe strategies for data storage, disaster recovery, and data exchange.
- Make use of public repositories containing public imaging data.
- Apply simple imaging analytics on a single image and multiple image collection
- Recognize potential privacy concerns related to the collection and use of, in order to make image processing practices safe and secure.
- Describe emerging privacy-preserving technologies to safely access and analyse large and small image data collections.

Recommended reading

- Ranschaert, E.R., Morozov, S., & Algra, P.R. (Eds.). (2019). Artificial Intelligence in Medical Imaging: Opportunities, Applications and Risks. Springer. https://doi.org/10.1007/978-3-319-94878-2
- Bui, A.A.T., & Taira, R.K. (Eds.). (2009). Medical Imaging Informatics. Springer. https://doi.org/10.1007/978-1-4419-0385-3
- Branstetter, B.F. (Ed.) (2010). Practical Imaging Informatics. Foundations and Applications for PACS Professionals. https://doi.org/10.1007/978-1-4419-0485-0

MIE2003
Period 1
2 Sep 2024
25 Oct 2024

Imaging Engineering

Print course description
ECTS credits:
6.0
Coordinator:

- G. Paiva Fonseca

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Assignment, Computer test, Written exam
Faculty of Science and Engineering

Magnetic Resonance Technologies

Full course description

The techniques of Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) are powerful, extremely flexible, and constantly developing tools in many application areas. This includes not least its use in medical routine and research. By appropriate manipulations of the nuclear spins, information can be gained about molecular structure, local molecular environments, flow and diffusion processes, and even such things as measurements of brain activation. An advantage of MRI over x-ray based imaging modalities in clinical applications is the excellent soft tissue contrast that is the achieved without any harmful ionizing radiation. This course provides you with the knowledge and skills to design, conduct and analyse NMR and MRI experiments. This theoretical and practical understanding also serves as foundation for a professional career in the field of NMR or medical imaging with MRI, or taking up a subsequent research career.

Course objectives

After completing this course, you are able to:

- Understand the fundamentals of Nuclear Magnetic Resonance (NMR): the phenomenon itself, spin dynamics and signal behaviour (e.g. relaxation times) and
- Evaluate the NMR signal and its relation to sample properties and subsequently predict how this can be manipulated to induce signal contrast.
- Explain how localised signals (Magnetic Resonance Spectroscopy) can be acquired using specific hardware such as local radiofrequency coils and magnetic field gradients, and how these gradients can be used to create special encoding, i.e. form an image (Magnetic Resonance Imaging).
- Explain the application of the main MRI pulse sequences in clinical and research applications, including anatomical and functional imaging, such as T1 and T2 anatomy, brain function (fMRI), angiography, diffusion and Quantitative Susceptibility Mapping.
- Assess the benefits and limitations of modern magnet design, by understanding the effect of magnetic field strength with relation to signal properties and scanning limitations.
- Avoid and minimize image artefacts and (the sources of) distortions by understanding relevant techniques to address the limitations of MRI.
- Employ different techniques and analyse the resulting data, including morphometry, image registration, image segmentation, fMRI data analysis and diffusion tensor/fibre tracking.
- Critically evaluate new developments in the field of Magnetic Resonance Technologies and

communicate these to an audience of experts and non-experts.

Recommended reading

Mandatory:

- Bernstein, M.A., King, K.F., & Zhou, X.J. (2004). Handbook of MRI Pulse Sequences. Elsevier.
- Callaghan, P. T. (1993). Principles of Nuclear Magnetic Resonance Microscopy. Oxford University Press.
- McRobbie, D.W., Moore, E.A., Graves, M.J., & Prince, M.R. (2017). MRI from Picture to Proton (3rd ed.). Cambridge University Press. https://doi.org/10.1017/9781107706958

Recommended:

- Schmitt, F., Stehling, M.K., & Turner, R. (1998). Echo-Planar Imaging: Theory, Technique and Application. Springer. https://doi.org/10.1007/978-3-642-80443-4
- Uludağ, K., Uğurbil, K., & Berliner, L. (Eds.). (2015). fMRI: From Nuclear Spins to Brain Functions (Vol. 30). Springer. https://doi.org/10.1007/978-1-4899-7591-1

MIE2004
Period 1
2 Sep 2024
25 Oct 2024
Print course description
ECTS credits:
6.0
Coordinator:

- A.B. Poser

Teaching methods:
PBL, Lecture(s), Skills
Assessment methods:
Presentation, Portfolio, Written exam
Thesis
Faculty of Science and Engineering

Master Thesis Research

Full course description

The curriculum of the master culminates in a master thesis. This part of the curriculum is your final proof-of-capability. It allows you to demonstrate that you have gained sufficient knowledge, competences and skills to perform independent scientific research and/or research-based engineering within your specialisation in instrumentation imaging engineering or molecular imaging engineering. You either conduct an entire scientific cycle or a research-based engineering design cycle. The scientific cycle consists of analysing lacking knowledge, formulating a hypothesis, drafting a research plan, executing experiments and reporting. The research-based engineering design cycle consists of formulating a problem, setting the design requirements based on scientific evidence, generating a concept and provide the (most) optimal solution.

Imaging Engineering

The master thesis comprises 32 weeks of work and accounts for 48 EC of your degree. The number of weeks and EC allow you to contribute to the field of molecular imaging and engineering with your research and/or research-based engineering. During the master thesis, you prepare for the next step in your career, in line with your knowledge, competencies and personal.

Course objectives

During the master thesis, you complete the following tasks:

- write a proposal, which includes a clear scientific background overview on the thesis topic (including knowledge gaps), research question or aim, hypothesis, relevant contexts, the design requirements and a manageable project plan (methods, analysis, equipment, time etc.);
- execute the research and/or engineering plan and troubleshoot encountered problems to improve and develop the project;
- analyse and process data and/or possible engineering solutions and report the results, discuss results in the context of the existing literature in the field, and elaborate conclusions in a written master thesis;
- present and defend the thesis project in an oral presentation.

Recommended reading

Will be discussed with your thesis coordinator.

MIE5000
Semester 2
3 Feb 2025
4 Jul 2025
Print course description
ECTS credits:
48.0
Coordinators:

- R.M.A. Heeren
- K. Saralidze

Teaching methods:
Research
Assessment methods:
Final paper, Presentation